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Optimization of Jute Fibre Content in Concrete Slabs having GFRP Rebars against Impact Loading

by

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A thesis submitted in partial fulfillment for the degree of Master of Science

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I want to dedicate this work to my friends, family and teachers, who helped me throughout my education .

CERTIFICATE OF APPROVAL

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Abstract

In developing countries, residual wastes, obtained from small or large-scale productions, are continuously gaining the attention for production of sustainable materials. Reinforcing the concrete with fibers (natural,artificial or hybrid) would able to capture the attention of the construction industry for the adoption of eco-friendly material composites. Natural fibers (especially Jute fibers) can have the ability to enhance the concrete performance in terms of energy absorption capacity or impact resistance. Structures that are susceptible to unprecedented event, such as blast, are supposed to have the ability to absorb the high impact energy.

In current study, the impact resistance of concrete slabs , having GFRP rebars and steel rebars have been inverstigated.Furthermore,these slabs are reinforced with different percentages of jute fibers (i.e. 1 %,3 % and 5%) by mass of cement as an additive for optimization of jute fiber content.A total of 32 slabs of size 450 mm x 225 mm x 75 mm are prepared. Jute fiber having a length of 50 mm is used. 6mm diameter of steel and GFRP rebars are used. Mix design ratio of 1: 2: 3: 0.6 (Cement: Sand: Aggregates: w/c) is considered. Impact tests are conducted by using simplified drop weight apparatus for two categories, i.e. low height impact and high height impact. The outcomes of SP are assigned a reference value for comparison with other combination.Basic dynamic properties are calculated.

All the specimens having jute fibers as an additive, show its superiority over concrete specimens in terms of toughness, energy absorption and post cracking ability. Toughness index in case of split tensile and flexural strength, the values obtained for 3% and 5% fiber content are almost equal. The combination of GFRP with 3% fiber content GJ3 and combination of steel with 5% fiber content SJ5 perform better in terms of impact resistance against low and high height impact. The compressive strength of 5% fiber content specimen is greater than 1% and 3% fiber content,respectively. The split tensile strength and flexural strength of 3% fiber content specimen is greater than 1% and 5% fiber content,respectively. The efficiency of jute fibers with GFRP and steel rebars against impact loading is justified as greater value of damping has been observed in all jute fiber specimens at different damages stage when compared with PC specimen. The probable

trend of toughness index against fiber content can be explored by empirical relation developed. The probable trend of damping against Impact capacity (No. of Blows) can be explored by empirical relation developed. Stronger the fiber concrete bond, greater will be resistance against the defragmentation of concrete. A comprehensive investigation is needed to know all other aspects of jute fiber reinforced concrete such as durability and bond matrix between concrete and GFRP rebars for its application in construction industry.

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Abbreviations

A_f	Cross-sectional Area of Rebar
b	Unit Width
c / $\mathbf{c}_b$	Depth of Compression Zone at Balanced Strain Condition
CFRC	Coconut Fiber Reinforced Concrete
CTI	Compression Toughness Index
d	Effective Depth
$\mathbf{E}_a$	Energy Absorption till Maximum Load
$\mathbf{E}_b$	Cracked Energy Absorption till Ultimate Failure
$\mathbf{E}_{total}$	Total Energy Absorption Failure
FTI	Flexural Toughness Index
FC	First Crack Strength
FRC	Fiber Reinforced Concrete
FRP	Fiber Reinforced Polymer
FS	First Strike
GP	Glass Fiber Reinforced Concrete
GJ1	Glass Fiber Reinforced Concrete with 1% jute fiber content
GJ3	Glass Fiber Reinforced Concrete with 3% jute fiber content
GJ5	Glass Fiber Reinforced Concrete with 5% jute fiber content
$\mathbf{M}_n$	Moment Capacity
IF	Impact Force
IM	Impact Mass
$\mathbf{RF}_{long}$	Longitudinal Frequency
$\mathbf{RF}_{Tran}$	Transverse Frequency
$\mathbf{RF}_{Tor}$	Torsional Frequency
STI	Split Tensile Strength

SP	Steel Reinforced Concrete
SJ1	Steel Reinforced Concrete with 1% jute fiber content
SJ3	Steel Reinforced Concrete with 3% jute fiber content
SJ5	Steel Reinforced Concrete with 5% jute fiber content
P_{max}	Maximum load
TI	Toughness Index

Symbols

ϵ_{cu}	Ultimate Compressive Strain in Concrete
ϵ_{fu}	Ultimate Tensile Strain of FRP
σ	Stress
ϵ_o	Strain at Peak Load capacitance
Δ	Deformation / Deection
ξ	Damping Ratio

Chapter 1

Introduction

1.1 Background

A bridge is an essential structure designed to cover a physical barrier, providing passage over the hindrance, something that can be unfavorable to cross otherwise. A bridge is usually made up of by combination of different structural members i.e. Pier, abutments, deck, girder etc. Like other important components, bridge deck is one of the most important structural members, whose failure can destroy its main functionality. Therefore, due to suicide / grenade explosion, Reinforced concrete members are extremely susceptible to severe strain rate loads [1, 2]. Quantifying the Concrete quality against impact loading in terms of sequence of cracking, extent of fragmentation, rate of strain and deformation [3]. The structure and its inhabitants can be protected against blast activity by utilizing the energy- dissipating method [4]. Impact resistance (IR) is an important factor to provide Structural safety against impact / impulsive loading.The ability of concrete to withstand impulsive loading without cracking is impact resistance (IR). [5]. Therefore, desired properties in concrete are impact resistance and energy absorption for resistance against impact loading. Reduction in maximum displacement can be obtained by enhancing reinforcement ratio in slab or by using the concept of doubly reinforcement concept [6]. Dynamic and static properties of concrete can be enhanced by reinforcing it with fibers [7]. Therefore, fibers are using in composites due to their

ability to contribute to sustain concrete strength and bearing strain rate.
To the best of authors knowledge, no research has been done for optimization of jute fiber content in concrete slabs having GFRP rebar against impact loading for its application in bridge deck by using simplified impact apparatus. Hence, an experimental study is planned to investigate for optimization of jute fiber content against impact loading.

1.2 Research Motivation and Problem Statement

Blast incidents on bridge deck is an important issue regarding the safety of structures.Bridges are built to span a physical hindrance.Bridges provide a way to cross a physical hindrance i.e. body of water, valley, or a road without closing the way underneath. The bridge slab may or may not sustain the impact of blast and launch debris as well as close the passage. Thus, the performance of reinforced concrete bridge deck needs to be investigated under blast loading.
Thus, the problem statement is as follow.
Impact resistance of normal concrete in terms of toughness against blast loading is a point of concern. Concrete fragments usually lead to severe casualties. Avoiding spreading of concrete fragments due to blast pressure can reduce casualties. Optimizing the performance of fiber content against blast loading will help to achieve economy in term of cost and natural resources.

1.2.1 Research Questions

How the optimization of fiber effect the mechanical properties?

What is the advantage of optimization of fiber content?

How dynamic properties of JFRC specimens have better performance than PC?

How optimzation will help us achieving economy?

1.3 Overall Objective Of the Research Program and Specific Aim of MS Thesis

The ultimate purpose of the research program is to replace longitudinal steel rebar with GFRP rebar in concrete structures with additional use of natural fibers for improved durability and performance.
The specific aim of this MS research work to investigate impact resistance of prototype reinforced concrete bridge deck in laboratory for optimizing the performance of jute fibers and steel bar replacement with GFRP rebar.

1.4 Scope of Work and Study Limitations

32 slabs are prepared for conducting impact test by using two different types of reinforcing rebars (Steel and GFRP) having different jute fiber contents. Two types are categorized into impact measures, i.e. low height and high height. Impact testing of steel reinforced concrete (SP) slabs, steel reinforced concrete with distinct jute fiber material (SJ1(1%)), (SJ3(3%)) and (SJ5(5%)).GFRP reinforced concrete (GP), GFRP reinforced concrete having different jute fiber contents (GJ1(1%)) , (GJ3(3%)) and (GJ5(5%)) .The results of SP are taken as reference.
The emphasis of current study is relative comparison. The current study is limited to impact testing, investigating basic dynamic properties (damping ratios and fundamental frequencies) and empirical modeling. The drop-weight test is used to assess impact resistance across simplified boundary conditions. Based on experimental output,basic linear relationship are developed.However,non linear relationship are not focused due to less number of variables considered in current pilot study for optimization. The other characteristics like co-relation of prototype and impact mass ,analysis of bond between concrete and GFRP rebar and performance of jute fiber reinforced concrete at large scale level are not part of current study.The drop weight used in this study remains constant.Only variation in heights in considered.Two types of height are used i.e.,650 mm and 950 mm.

1.4.1 Rationale Behind Variable Selection

The justification behind specification selection are:

- Due to high tensile strength, flexural strength and toughness jute fibre is preferably used.
- By studying satisfying results explored by different researchers, the ratio 1(C):2(S):3(A) and 1%, 3% and 5% of fibre content by mass of cement and 50mm length of fiber is used in current research work[8]. .
- GFRP rebars are used due to their resistance to corrosion, high tensile strength, light weight ,low maintenance cast and by reviewing previous literature[8].

1.5 Brief Methodology

In this experimental program, determination of mechanical as well as dynamic properties of plain concrete (PC) and jute fiber reinforced concrete (JFRC) having different jute fiber contents are done. The mix design ratio for current research is 1(cement):2(sand):3(aggregate):0.6 (w/c). Length of 50 mm for jute fiber is used. 1%,3% and 5% by cement mass are used for preparation of JFRC samples. Slab having size 450 mm x 225 mm x 75 mm are prepared. The specimens are tested for impact resistance and dynamic properties.Based on experimental findings, empirical equations are predicted for determination of impact resistance.

1.6 Thesis Outline

There are six chapters in this thesis, which are as follows:
Chapter 1 consists of introduction section, research motivation, problem statement, overall goal and specific aim, scope of work, study limitations, brief methodology and thesis outline.

Chapter 2 contains the literature review section. It consists of background,use of small linear natural fibers in concrete for improved efficiency, use of GFRP rebars for better resilience in concrete structural parts, experiments and impact test strategies, novelty of current research project and summary.

Chapter 3 consists of experimental program. It contains background, raw ingredients, the method of casting ,basic mechanical Properties of PC and JFRC, details of slab specimens and labeling scheme, testing methodology and summary.

Chapter 4 consists of experimental figure. It contains background, impact capacity, Dynamic properties at various levels of damage.

Chapter 5 comprises of discussion. It contains background,Empirical modeling for the relationship between toughness index and fiber content,Empirical modeling for the relationship between damping and impact strength and summary.

Chapter 6 includes conclusion and recommendations. Bibliography is presented right after chapter 6.

Chapter 2

Literature Review

2.1 Introduction

Blast engineering regarding civil infrastructure, although very crucial in this modern era, has only received rapidly evolving interest in recent time, and many areas in this field, including most of the aspects regarding bridges, demand intensive attention. Impulsive or Impact loading due to any unpredicted events such as explosion or any act of terrorism will produce unexpected stresses and deformation in a structure. This is due to the scattering of high intensities forces in the form of waves after explosion or blast. Thus, it will cause the reduction in material strength which further lead to defragmentation of material from structure or initiate failure mode of concrete structures.

2.2 Performance Improvement in Concrete by Utilizing Small Discrete Natural Fibers

Fibers, when added in concrete as an additive will act to provide cracking resistance against static and dynamic loading [9]. Although, performance of concrete improves by inclusion of synthetic fibers. The synthetic fibers is extracted from unrenewable and costly natural resources [10]. Improvement in mechanical results of cementitious composites of concrete will be obtained by addition of jute fibers and jute yarns of particular length and content as an additive [11]. The addition of Jute fibers in cementitious concrete will act to provide improvement in concrete efficiency [12]. The industrial activities for cement production globally emit carbon around 5% [13] that represents it as inferior component of concrete for its ecological effects [14]. An obvious amount of cement content by weight can be saved by reinforcing of fibers in concrete by mass of cement [15]. Microcracking along with delay in crack initiation can be reduced by using suitable jute fiber content and length [16]. Greater resistance against projectile impact will be achieved by using more fiber length and percentage [17]. The positive impact on mechanical properties can be achieved by using JFRC with greater fiber content by increasing curing time/age [18]. The compressive resistance of JFRC against freeze-thaw cycles decreases when compared with PC [19].The tension zone concrete due to its low contribution is neglected in ACI 318-14 [20] for calculation of reinforcement.

Table 2.1: Jute Fiber Mechanical Properties[21, 22]

Mechanical Properties					
Length (mm)	Diameter (μm)	Density (kg/m3)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max Elongation %
1.5-120	20-200	1300-1490	320-800	8-78	1-1.8
–	40-350	–	29-312	–	19

$$M_N = [\rho b d f_y \times (d - \frac{\beta c}{2})] + T_f(\frac{d + c - \beta c}{2}) \tag{2.1}$$

The modified version of equation proposed by [23] is used by Hussain and Ali [24] for incorporating the JFRC effect in tension zone of concrete. The value of 'T_f' will be the taken as 50 % load difference between PC and JFRC.Jute fibers mechanical properties stated by [21, 22] are shown in table 2.1

2.3 Durability Improvement in Structural Concrete Members by Use of GFRP Rebars

In terms of high strength, light weight and non-conductive character, fiber reinforced polymer (FRP) rebars are advantageous over steel rebars. Usually, mechanical properties such as final stress and strain are compromised due to steel corrosion.Glass fiber reinforced polymer are more ductile and cheaper than carbon fiber[25].Hence,it can be considered as an alternative solution to repair and strengthen concrete element.That's why,GFRP rebars are selected to start with. Hence, prompting due to its greater resistance against corrosion and fatigue loading, the use of fiber reinforced polymer (FRP) rebars such as glass fiber reinforced polymer (GFRP) rebars .On the other hand where high ductility is required steel rebars are preferred over GFRP rebars due to its lack of ductility [25].Steel rebars are advantageous over GFRP due to their bending property where sufficient anchorage is required [26]. In GFRP rebars of reinforced concrete, greater post cracking reinforcement strains are found before failure by lower axial flexibility [27].The bond strength present in flowable fiber-reinforced engineered cementitious composites with embedded GFRP rebars is more than in convectional concrete [28]. The resistance against dynamic forces greatly depends upon the geometrical properties and total mass. Inertial forces comes into play along with the contribution of bending behavior [29]. Rebars plays an important role in contribution to concrete strength against impulsive load. Although, ACI440.1R-15 [30] prohibits the use of FRP rebars such as GFRP for design of compression members but the strong literature development in future may results in future approval by International codes.There is no validation of reinforcement design against GFRP rebars in ACI 318-14 [20].Therefore, calculation for moment capacity of concrete having GFRP rebars is done by using formula presented in [30].Hence GFRP due to light weight and corrisionless nature,are preferable over steel rebars.

$$M_N = A_f f_{fu} \times (d - \frac{\beta_1 C_b}{2}) \tag{2.2}$$

$$C_b = \frac{\varepsilon_{cu} \times d}{\varepsilon_{cu} + \varepsilon_{cu}} \tag{2.3}$$

Where c_b = Compression zone depth at balanced strain condition. It will be calculated as

$$M_N = A_f f_{fu} \times (d - \frac{\beta_1 C_b}{2}) + T_f(\frac{d + c - \beta c}{2}) \tag{2.4}$$

Ejaz and Ali [31] recommended an equation for calculating moment capacity of JFRC having reinforcement as GFRP rebars. The value of T_f will be taken as 53 % of the load difference between PC and JFRC.

2.4 Prototypes and Their Impact Test Mechanism

Previous researchers conducted an experimental study on FRC by using concept of full-scale testing, scaled down prototype testing according to their scope of work. It can be seen in table 2.2, the different impact test approaches along with their prototypes used by different scholars to study the impact/impulsive resistance of FRC. Ahmad and Ali [8] used the modified pendulum approach to study the impact resistance of concrete wall having GFRP rebars. Li et al. [32] Using the bullet projectile impact method, the analysis was performed on ultra-high-performance fiber reinforced concrete disks to examine the penetration depth and impact pattern. Hussain and Ali [24] conducted the study on JFRC slabs by using simplified free fall method of drop weight to determine the impact resistance of slabs.Liu et al.[33] conducted the study on ultra-high-performance concrete (UHPC) cylinders by using cartridge projectile impact mechanism. Wang and Chouw [34] use the technique of drop weight for investigating the flexural performance of coconut fiber reinforce in concrete under impulsive load. Mastali et al.[35] investigated the impact resistance of self-compacting concrete cylinders reinforced with recycled GFRP by using the drop weight approach.

TABLE 2.2: Previous prototypes study related to impact test

Reference	**Ahmad and Ali (2020)**	**Li et al.(2020)**	**Hussain and Ali(2019)**	**Liu et al.(2018)**	**Wang et al.(2018)**
Impact Mechanism	Modified Pendulum Impact	Bullet Projectile Impact	Free falling drop weight	Catridge Projectile Impact	Drop weight Instrumental
Impact Weight/Velocity	2.215 & 2.92 Kg	843 & 926 m/s	1.25 kg	500-800 m/s	48 Kg
Prototype Specifications	JFRC wall with GFRP and Steel Rebars 375 x 375 x 50 mm	UPFRC Disks 12 x 300 mm	JFRC Slabs 430 x 280 x 75 mm	UHPC Cylinders 750 x 700 mm	CFRC Beams 100 x 100 x 500mm
Outcome	No. of Blows	Penetration Depth & damage pattern	No. of blows	Crater Diameter volume loss & penetration depth	Force time history, Energy absorption

Pham and Hao [36] recommended an equation for calculation of bending moment under impact loading. They reported that a shear damage will be experienced by a member under impact load if flexural damage has been initiated under static loading. The bending moment diagram for simply supported support condition is shown in Fig.2.1 under static and impact load.

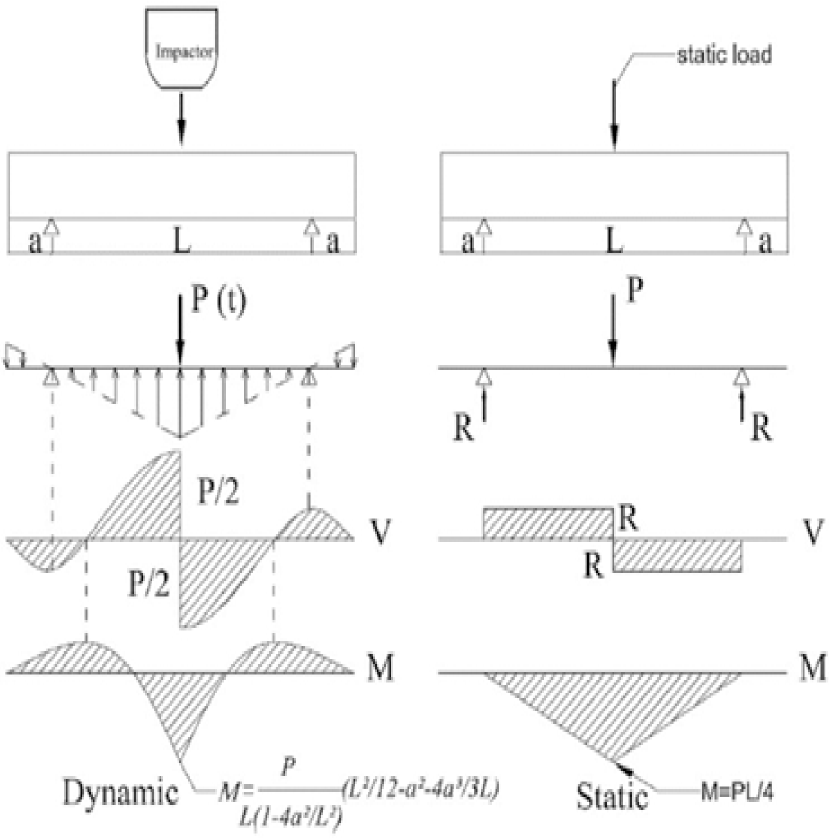

FIGURE 2.1: BMD under static load and impact load for simply supported condition Pham and Hao [36]

2.5 Novelty of Current Study

There are two impact test techniques, depend upon kinetic energy,which were describes in ACI 544.2R-89 [37].It can be seen in Figure 2.2. One is free fall of weight test method and other is Charpys pendulum method.The direction of weight is parallel to the weight of slab acting downward in case of free fall method while the direction of weight is perpendicular to the weight of slab acting downward in case of Charpys pendulum method. For both approaches, quantitative evaluation in terms of energy absorption capacity of structure is done by estimating the sum of repetitive blows. This help to conduct the relative comparative study between FRC and normal concrete specimens. To the best of authors knowledge, no work has been done for optimization of jute fiber content in concrete slabs having GFRP rebar and steel rebar against impact loading by using drop weight

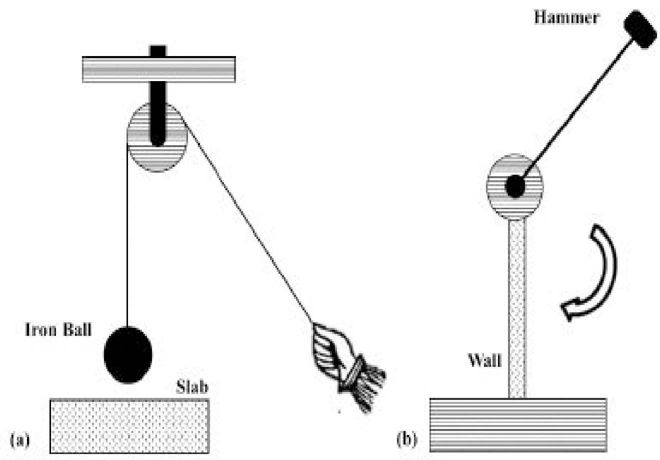

FIGURE 2.2: Simplified Impact test methods [8, 24].

impact apparatus. Hence, an experimental study is planned to investigate for optimization of jute fiber content against impact loading to achieve economy.

2.6 Summary

Investigation against impact resistance can be achieved with higher accuracy by using the state-of-the-art equipment as compared to prototype testing done with simplified boundary condition. The concrete behavior prediction against impulsive/impact loading can be done by conducting full scale field testing and prototype testing in laboratories.Empirical relationships will be developed with identifying error percentages for performing simplified testing. GFRP rebars being advantageous over steel rebars in terms of light weight and rust resistant. Researchers supports the addition of fibers as an additive in concrete for improving the impact resistance. Inclusion of natural fibers in concrete plays an important role in improving performance of concrete against impact loading.

Chapter 3

Experimental Program

3.1 Background

In case of blast activity or terrorist attack, bearing balls (having high velocity) scatter in arbitrary direction. Due to scattering, the nearby structures experience forces. This happening causes damage to nearby structure in terms of cracking and debris scattering as shown in Fig.3.1. The capability of reinforced concrete structures to withstand such extreme impulsive or impact loading greatly depends upon the characteristics dealing with dynamic behavior, pattern of cracking and scattering range of debris [38, 39].

The energy absorption capacity of concrete enhances by reinforcing the concrete with fibers. In addition to that, enhancement in post-failure strength can also be achieved. Also, brittle type failure will be converted to ductile failure by reinforcing with fibers. The carrying capacity of GFRP rebars is about the same as that of conventional steel rebars, but in terms of corrosion resistance, GFRP rebars are preferable over steel rebars. Hence GFRP rebars are more favorable in an moist environment. Hence exploring the behavior of concrete against impact loading by reinforcing it with jute fibers and GFRP rebars. This has been done by conducting experimental study. Raw ingredients used, mix design along with casting procedure, mechanical properties as well as basic dynamic properties,slab specimens with their labels and testing procedure have been discussed in detail.

FIGURE 3.1: Probable scenario of blast/terrorist activity on bridge.

3.2 Raw material/Ingredients

For preparation of specimens for PC, JFRC along with their prototypes, ordinary Portland cement, locally available jute fiber, lawrencepur sand and coarse aggregates 12.5 mm down were used as an ingredient. Generally, jute fibers are locally available in raw form. Then it is sliced into length of 50mm for usage. Then it is put into water for 24 hours for impurities removal. Locally available raw fibers and fibers having 50mm cut length can be seen in Figure 3.2a and 3.2b, respectively. There will always be fibers pull out or breakage of fibers under tension failure. Hence for studying fiber resistance against tensile failure and fiber behavior under such failure,50mm cut length of fiber is taken along with hypothetically assuming that half of fiber length will remain entrenched in concrete and half will spall up at ultimate failure stage.6mm diameter steel rebars as well as GFRP rebars having length of 450 mm and 225 mm are utilized as reinforcement as shown in Figure 3.3a and 3.3b respectively.Figure 3.3c and Figure 3.3d represents the relative behavior

FIGURE 3.2: Jute fibers; a) raw fibers, b) fiber cut length

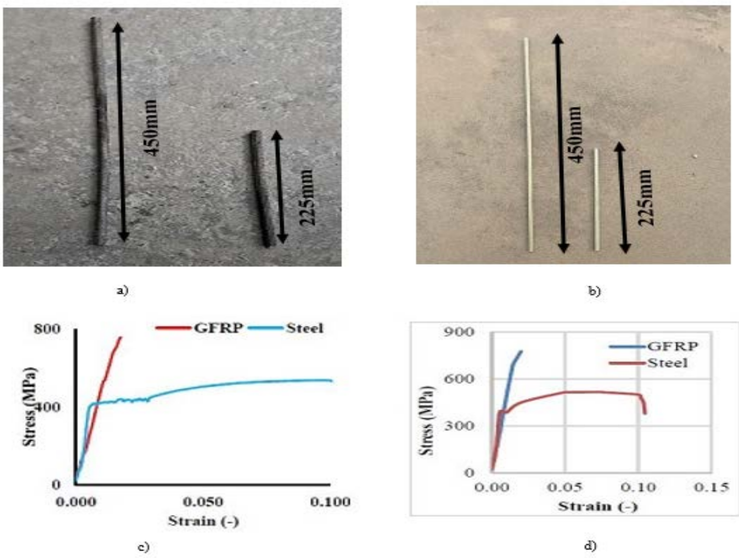

FIGURE 3.3: Jute fibers a) Steel rebars, b) GFRP rebars, c) Tensile Strength [8] , d) Tensile Strength [40]

against tensile strength of both rebars reported by [8, 40]

3.3 Specimens Preparation and Properties

3.3.1 Mix Design

For the specimen preparation of plain concrete (PC), mix design ratio utilized for cement, sand and coarse aggregate is 1:2:3 respectively.Water to cement ratio of 0.6

is utilized for above mentioned mix design. For the JFRC specimen preparation, same mix design is utilized. The cut length of 50mm for jute fiber is used. 1%,3% and 5% of jute fiber by mass of cement is use as an additive.Water to cement ratio of 0.68 is utilized for JFRC Specimens as jute fiber has high water absorption capacity[8].Both workable mixes are compacted properly for obtaining good strength and results. The w/c ratio used for JFRC is referred as optimum because more water addition will be responsible for bleeding.This similar concept was use for preparation of CFRC by [41]. In current study, keeping in view the perspective of obtaining desired characteristics between matrix of concrete and fiber, dose of jute fibers desires fully related with mass of cement. Many researchers have been using Agrarian waste fibers of plants having higher pozzolanic reactivity as partial cement replacement. This was made possible because of high quantity consumption of minerals [41].The desired strength against above mentioned mix design is 15MPa.The purpose of targeting above mentioned strength is to achieve structural economy. The main intention is to achieve the increment in energy absorption capacity because in case of impact/impulsive loading energy absorption capacity is advantageous over compressive strength. Selection of fiber length, fiber content and water cement ratio have been done by reviewing previous literature related to FRC with the purpose of obtaining greater toughness [42–44]. Hence, for obtaining high energy absorption capacity in terms of impact resistance, reinforcing concrete with fibers in agricultural rich land can be an efficient solution.

3.3.2 Casting Procedure

In case of specimen preparation of JFRC, all dry ingredients are to be added in layers. Starting with coarse aggregates layer in one third proportion, followed by a fibers layer are inserted in the mixer.Then fine aggregates layer in one third proportion followed by a fibers layer is inserted in mixer. In the end, a layer of cement is placed above already placed layers. This process is repeated until all the required material for one batch is placed in mixer. After placement of all the ingredients, the mixer is rotated to about 4 minutes with insertion of required amount of water during whole rotation. The layering strategy is applied to avoid balling effect. By following specification of ASTM C143 [45], slump test is performed for examining the workability of prepared specimen. 55 mm, 39 mm, 36 mm and 35mm are the slump values observed in case of PC, Jute fiber with 1 %,3 % and 5 % content by mass of cement, respectively. For determination of dynamic and mechanical properties, cylinders and beamlets having dimension of 100 mm x 200 mm and 100 mm x 100 mm x 450 mm, respectively are casted. Also, filling and tamping was done by adopting the standard procedure. The specimens are demolded after 24 hours and soaked in water for 28 days for obtaining the desired properties. Water to cement ratio for FRC specimens have been selected by reviewing previous literature with a purpose of obtaining desired properties. By using standard procedure in ASTM C215 [46], dynamic properties are calculated by conducting dynamic testing.

3.3.3 Basic Dynamic and Mechanical Properties

The findings of dynamic behavior of specimens prepared are shown in Table 3.1. The damping ratio of JFRC cylinder having 5% ,3% and 1% fiber content by mass of cement is 6.2, 5.6 and 4.3 ,respectively, as noted in Table 3.1.

Similarly, the damping ratio of PC cylinder specimen is 4.1 which is 34%, 26%, and 5% less than the JFRC specimen with 5%, 3% and 1% fiber content, respectively. The damping ratio of JFRC beamlets specimen having 5% ,3% and 1% fiber content by mass of cement is 4.8, 4.5 and 3.3 respectively as noted in Table 3.1.
Similarly, the damping ratio of PC beamlet specimen is 3.2 which is 33%, 28%, and 4% less than the JFRC specimen with 5%, 3% and 1% fiber content, respectively. The dynamic elastic modulus of JFRC cylinder having 5% ,3% and 1% fiber content by mass of cement is 1.9, 2.15 and 2.27 GPa, respectively as noted in Table 3.1. Similarly, the dynamic elastic modulus of PC cylinder specimen is 2.4 GPa which is 21%, 11%, and 6.5% more than the JFRC specimen with 5%, 3% and 1% fiber content, respectively. The dynamic elastic modulus of JFRC beamlets specimen having 5% ,3% and 1% fiber content by mass of cement is 21.1, 25.4 and 23.3 respectively as noted in Table 3.1. Similarly, the dynamic elastic

TABLE 3.1: Dynamic Behavior of Specimens

Dynamic Properties	**Specimen Type**							
	Cylinders				Beamlets			
	PC	JFRC			PC	JFRC		
		1%	3%	5%		1%	3%	5%
$RF_{Lon}(Hz)$	2707± 948	2693± 800	2640± 954	2435± 1200	1620± 22	1580± 100	1508± 32.5	1309± 53
$RF_{Tran}(Hz)$	1509± 0	1400± 102	1301± 200	1334± 590	1598± 80	1464± 200	1376± 340	1331± 445
$RF_{Tor}(Hz)$	1620± 20	1397± 120	1355± 35	1309± 80	1553± 224	1464± 300	1353± 115	1331± 65
ξ %	4.1± 1	4.3± 0.8	5.6± 1.4	6.2± 1.3	3.2± 0.6	3.3± 0.8	4.5± 0.9	4.8± 0.2
$D_{EM}(GPa)$	2.4± 0.6	2.27± 0.1	2.15± 0	1.9± 2.1	31.9± 8.6	23.2± 14.4	25.4± 7.71	21.1± 7.01

modulus of PC beamlet specimen is 31.9 which is 32%, 20%, and 26% more than the JFRC specimen with 5%, 3% and 1% fiber content, respectively.

The outcomes of mechanical behavior of specimens prepared are shown in Table 3.2. Universal testing machine (UTM) is used for obtaining results for mechanical properties i.e., Compression, split tension and flexural properties of specimens. The specimens are tested according to ASTM standards C39 for compression [47], C496 for split tension [48] and C78 for flexural [49].

Under compressive behavior, the compressive strength of JFRC with 1%,3% and 5% jute fiber content comes out to be 6 MPa,5.3 MPa and 7 MPa respectively which is almost 50% less than PC specimens i.e., 14.6 MPa. The strain value of JFRC with 1%,3% and 5% comes out to be 0.0261,0.034 and 0.021, respectively

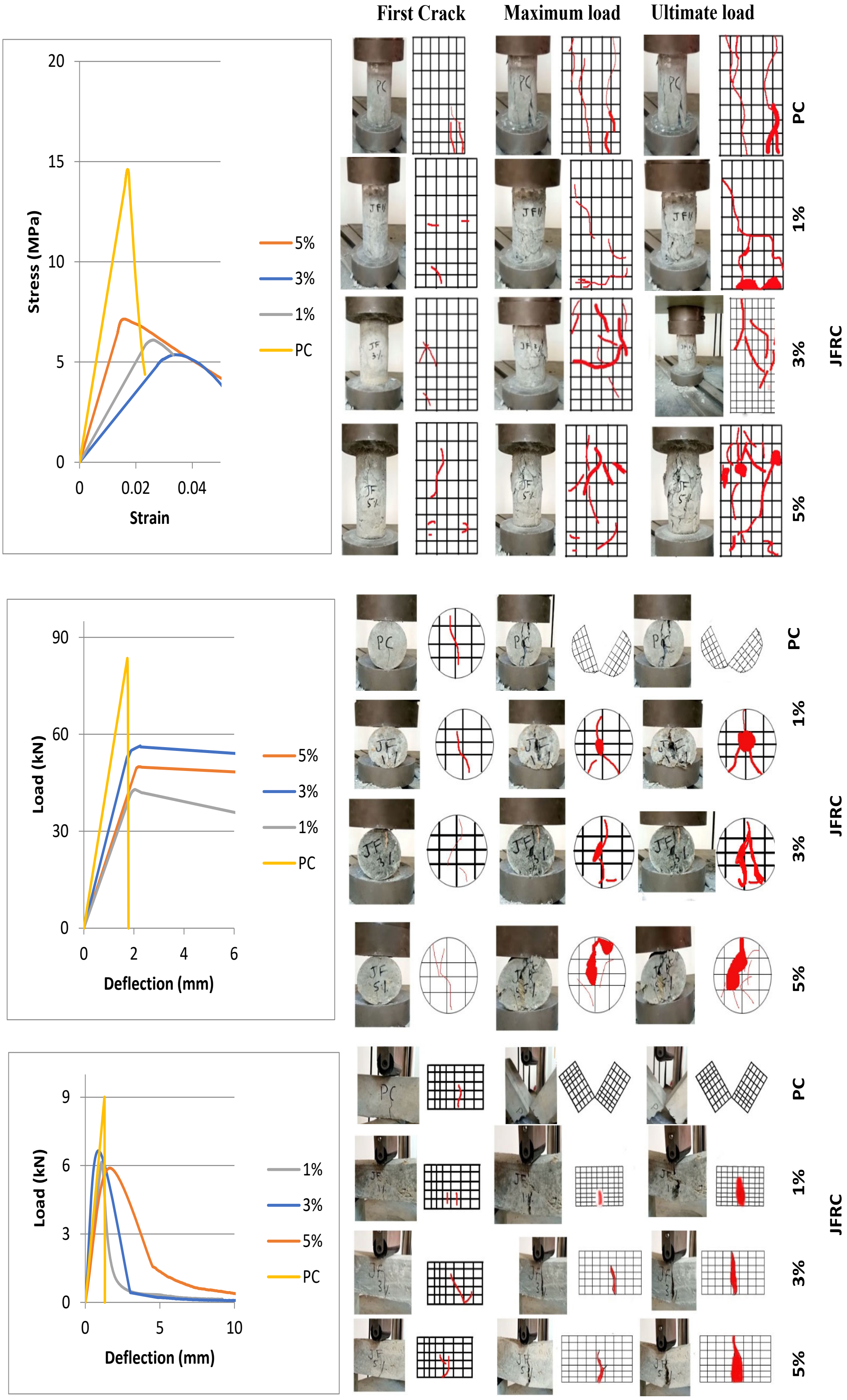

FIGURE 3.4: Mechanical Properties along with Cracking Pattern
a) Compressive, b) Split-tension, c) Flexure

Table 3.2: Compression, Split-Tension and Flexural Properties of PC and JFRC Specimens.

Properties	**Compression**				**Split Tension**				**Flexure**			
	PC	JFRC			PC	JFRC			PC	JFRC		
		1%	3%	5%		1%	3%	5%		1%	3%	5%
P_{max} (KN)	114.6	47.8	42.1	56.08	83.5	42.9	56.4	49.9	9	6.1	6.6	5.88
σ (MPa)	14.606	6.0	5.364	7.145	2.66	1.37	1.8	1.59	6	4.15	4.5	4
ϵ	0.017	0.0261	0.034	0.021	-	-	-	-	-	-	-	-
Δ	-	-	-	-	1.17	2.04	2.2	2.2	1.2	1.1	0.86	1.5
E_a	0.0852	0.06	0.099	0.124	2.31	2.1	2.38	1.85	5.8	3.5	2.8	4.6
E_b	0.04	0.243	0.119	0.056	0	7.5	14.7	13.3	0	6.3	8.8	16.8
E_{total}	0.126	0.304	0.219	0.18	2.4	12	17.1	15.2	5.8	9.8	11.7	21.5
TI	1.448	1.48	2.19	4.98	1.0	5.44	7.18	8.2	1	2.78	4.08	4.68

which are 153%,200% and 123% greater than the strain value of PC is 0.017 at peak load. The energy absorption of JFRC having 1%,3% and 5% jute fiber content up to peak load are 0.06 $MJ/m^3, 0.09MJ/m3, 0.124MJ/m3$, respectively. The energy absorption of PC up to peak load is 0.0852 MJ/m^3 which is 30% greater than JFRC specimen with 1% fiber content but 6% and 45% less than JFRC specimen with 3% and 5% fiber content, respectively. The toughness Index of JFRC specimens with 1%,3% and 5% fiber content comes out to be 1.48, 2.19, 4.98, respectively, which is greater 102%, 151% and 343% greater than PC having toughness index of 1.448. Figure 3.4a is the graphical representation of mechanical properties under compression along with the different damages stages encountered. PC specimen encountered spalling of particles which shows the brittleness of PC at maximum load while only widening of crack have been observed in all combination of JFRC. This is due to the bridging capability of fibers which restrict the spalling. Under split tensile behavior, the split tensile strength of JFRC with 1%,3% and 5% jute fiber content comes out to be 1.37 MPa,1.8 MPa and 1.59 MPa, respectively. The split tensile strength of PC is 2.66 MPa which is almost 50%,33% and 40% greater than JFRC specimens with jute fiber content of 1%,3% and 5%, respectively. The total energy absorption of JFRC having 1%,3% and 5% jute fiber content comes out to be 12 J ,17.1 J and 15.2 J, respectively. The total energy absorption of PC specimen 2.4 that is 500%,712% and 633% less than the JFRC specimen with 1%,3% and 5% jute fiber content, respectively. Figure 3.4b is the graphical representation of mechanical properties under splitting tension along with the different damages stages encountered. Load deflection curve can be seen in Figure 3.4b. It can be observed that PC specimen takes more load than JFRC specimens but split into two parts after reaching peak load. JFRC specimens splits into two halves at ultimate load. This is due to strong bonding between fiber and concrete as well tensile strength of fiber which helps to achieve higher energy absorption capacity of JFRC specimens. The toughness Index of JFRC specimens with 1%,3% and 5% fiber content comes out to be 2.66, 7.18 and 8.2, respectively, which is greater 266%, 718% and 820% greater than PC having toughness index of 1. Under flexural behavior, the flexural strength of JFRC with 1%,3% and 5% jute fiber content comes out to be 4.1 MPa,4.5 MPa and 4 MPa, respectively. The flexural strength of PC is 6 MPa which is almost 32%,25% and 34% greater than JFRC specimens with jute fiber content of 1%,3% and 5%, respectively. The total energy absorption of JFRC having 1%,3% and 5% jute fiber content comes out to be 9.8J ,11.7J and 21.5J, respectively. The total energy absorption of PC specimen 5.8 that is 169%,201% and 370 % less than the JFRC specimen with 1%,3% and 5%jute fiber content, respectively. Figure 3.4c is the graphical representation of mechanical properties under flexural behavior along with the different damages stages encountered. Load deflection curve can be seen in Figure 3.4c. PC Specimen failed at peak load and divided in to two pieces. A small hair line crack has been observed in all JFRC Specimens. At peak load stage, the cracks get widened without breaking into pieces. At ultimate load stage, failure of JFRC specimens occurs. This is due to strong bonding between fiber and concrete as well tensile strength of fiber which helps to achieve higher energy

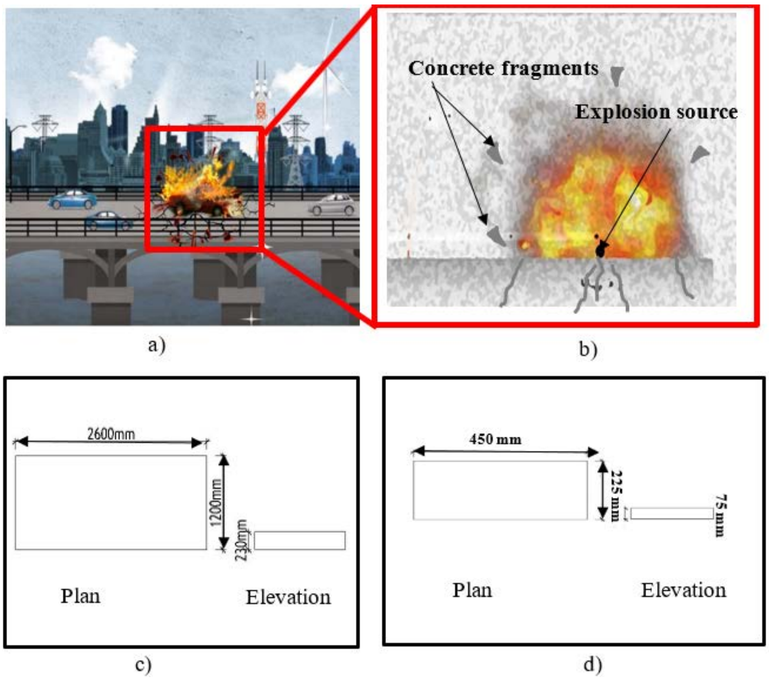

FIGURE 3.5: a) Blast Scenario, b) Area of Interest, c) Schematic Diagram of Slab, d) Prototype slab

absorption capacity of JFRC specimens. The toughness Index of JFRC specimens with 1%,3% and 5% fiber content comes out to be 2.78, 4.08 and 4.68, respectively, which is greater 278%, 408% and 468% greater than PC having toughness index of 1.Furthermore,it should me kept in mind that strength is not targeted. Main emphasis is high damping and impact resistance using different fibers contents in concrete for optimization.

3.4 Impact Testing Slab Prototype Specimens and Their Labelling

The blast/terrorist activity taken place on bridge deck is shown in Figure 3.5a. The area of interest after explosion is figured out in Figure 3.5 b, which show cracks in slab and scattering of concrete fragments after explosion. Figure 3.5 c represent the schematic diagram of slab and its prototype for conducting impact testing is shown in Figure 3.5d. The size of prototype slab is 450 mm x 225 mm x 75 mm for impact testing. Simplified boundary conditions have been used for conducting impact testing. No craters are observed in specimen after casting.

Impact testing have been categorized into two group, depending upon the height of drop weight i.e., low height impact (650 mm) and high height impact (950mm). The drop weight used for this purpose is 1.75 kg. Height is generally function of velocity. Low impact height means striking with low velocity as compared to high impact height which means striking with high velocity. For each combination of fiber and reinforcement, two slabs specimen are casted. The details of casted slab specimen along with their labelling can be seen in Table 3.3. Eight rebars of length 225 mm are present along longer side whereas 4 rebars of length 450 mm are present along shorter side. Hence each slab specimens contains a mesh of 8 x 4 rebars. The spacing is adjusted in such a way that size of center reinforcement cell is 75 mm x 75 mm where drop weight is likely to strike. The details of provided reinforcement in slab specimens can be seen in Figure 3.6.

TABLE 3.3: Slab Specimens Labelling

Test Variable	**Low Height**				**High Height**			
Impact Height	650 mm				950 mm			
PC	SP_A	GP_A	SP_B	GP_B	SP_C	GP_C	SP_D	GP_D
JFRC 1%	$SJ1_A$	$GJ1_A$	$SJ1_B$	$GJ1_B$	$SJ1_C$	$GJ1_C$	$SJ1_D$	$GJ1_D$
3%	$SJ3_A$	$GJ3_A$	$SJ3_B$	$GJ3_B$	$SJ3_C$	$GJ3_C$	$SJ3_D$	$GJ3_D$
5%	$SJ5_A$	$GJ5_A$	$SJ5_B$	$GJ5_B$	$SJ5_C$	$GJ5_C$	$SJ5_D$	$GJ5_D$

3.5 Testing Methodology

3.5.1 Simplified Impact Testing Procedure

The parameters like source, chemicals, weight of explosives and distance of explosion from source are the main factors which influence the real blast scenario. Its duplication requires specialized skill along with limitless resources. The current program aims to find out the efficiency of fiber addition in convectional concrete

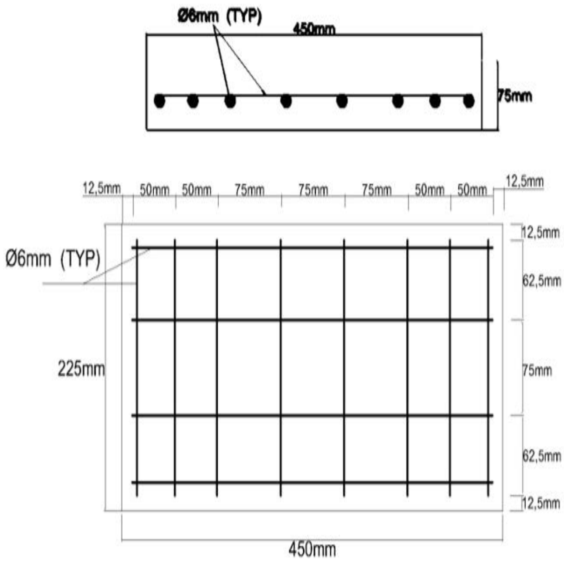

FIGURE 3.6: Slab Reinforcement Detail

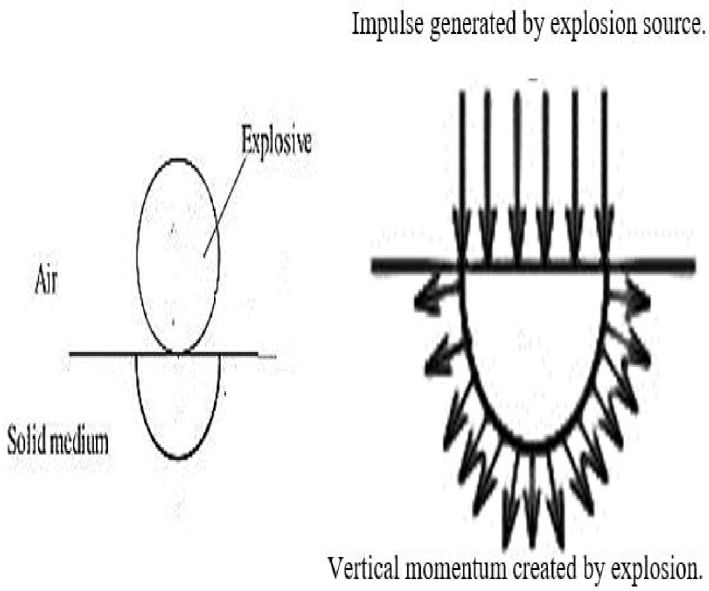

FIGURE 3.7: Contact Explosion on medium

and convectional steel rebars replacement with GFRP rebars against impact loading. Usually, in a blast event, blast Pressure is produced which will be more at the source of explosion. Figure 3.7 shows the impulse generated on the surface when explosion takes place. The vertical impulse generated by source of explosion will be equal to vertical momentum of a expansion body as shown in Figure 3.7 [50].

For current study, simplified Impact testing approach is applied for finding the impact resistance of a slab. This approach is suggested by [24] .Different drop height are used in current study i.e. 650 mm and 950 mm based upon which the relative terms i.e. low impact height and high impact height are assigned. Simple supported support condition has been employed for current study. The weight is dropped from the height of 650 mm and 950 mm before striking the specimens. The value of drop weight is kept constant. The values of drop height are changed to evaluate the damaging effect of slab by a little increment in impact velocity which is function of height. The impact strength can be quantified by counting numbers of blows/strikes in repetitive manner as reported by ACI 544.2R-89[35] so that defined level of distress have been achieved. This idea has been also employed by [8], [35],[24]. The different type of distress has been shown in Figure 3.8. Hence, the unit of impact capability/strength will be taken as number of strikes/blows.More number of strikes,more resistance against impact loading.

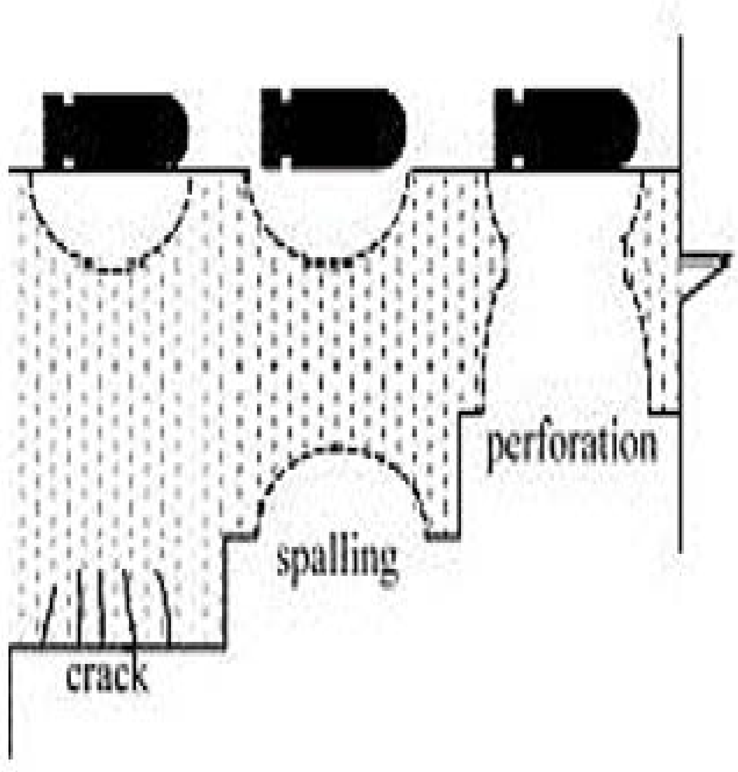

FIGURE 3.8: Distresses in slab after explosion or impact load

In current research program , two different impact heights are used for drop of an impact weight of 1.75 kg.This would produce impact on the specmiens.The impact values at first crack and ultimate failure(where complete cracking is observed on entire cross section or spalling depth of 25 mm is achieved).The results of SP are taken as reference.Figure 3.9 represent the test setup and schemaic diagram.

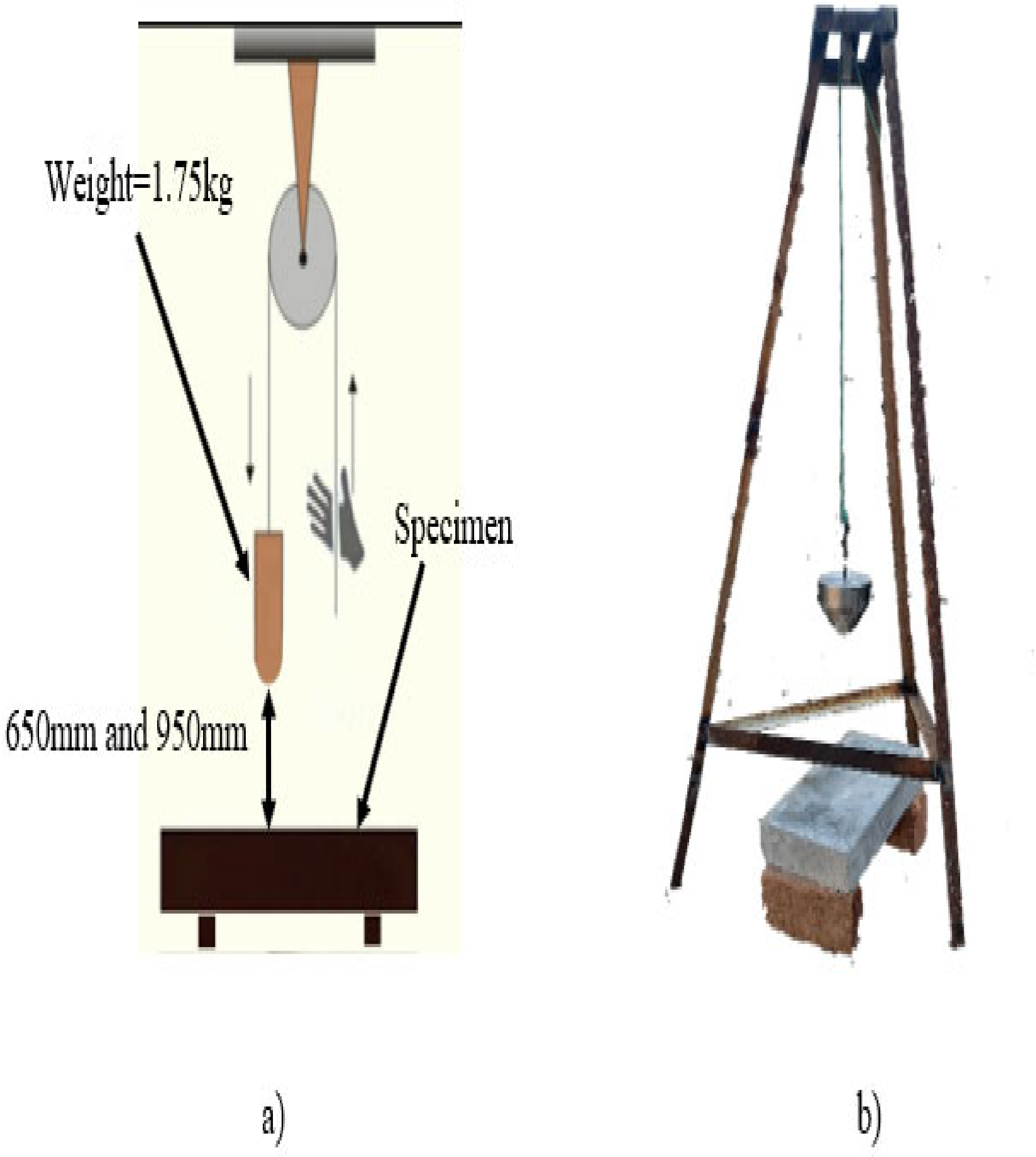

FIGURE 3.9: a) Schematic Diagram b) Test Setup

3.5.2 Calculation of Dynamic Properties

All the casted specimens are tested for only basic dynamic properties.By following specification mentioned in ASTM C215 [46], dynamic testing is performed before testing and after utlimate impact faliure for finding fundamental frequencies and damping ratios.The schematic diagram for finding respective fundamental frequencies is shown in Figure 3.10.The location of striking hammer and placement of sensor is also shown in Figure 3.10.The testing is done as per ASTM C215 [46].Only basic dynamic properties are calculated.

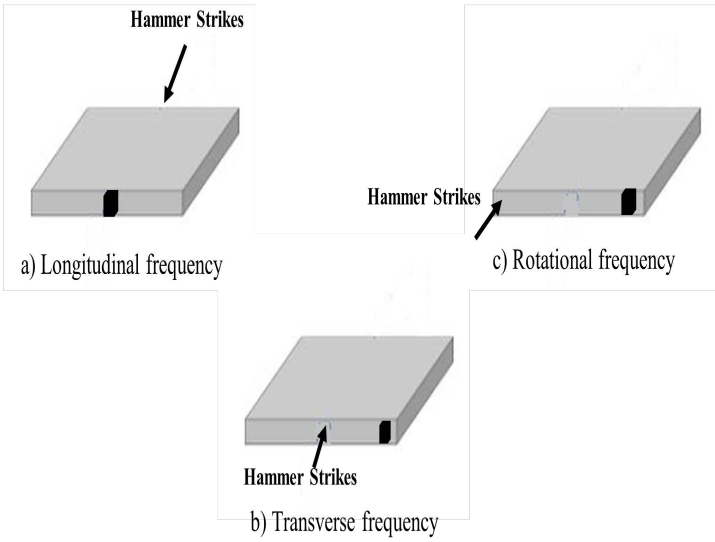

FIGURE 3.10: a) Longitudinal frequency b) Transverse frequency c) Rotational frequency as per ASTM C215

3.6 Summary

All specimens are prepared by using mix design ratio of 1:2:3 (Cement: Sand: Aggregate) and jute fiber content 1%, 3% and 5%, by mass of cement,is used,respectively.Water to cement ratio employed for above mentioned specimens is 0.6. Results of mechanical properties indicates that JFRC have greater energy absorption capacity as well as higher damping ratio than PC specimen.The total number of 32 prototype slabs having steel and GFRP rebar of 6mm diameter, as reinforcement are casted for conducting impact testing.

Chapter 4

Experimental Results

4.1 Background

All specimens are prepared by design ratio of mix as 1:2:3 (Cement: Sand: Aggregate) and jute fibers,1%,3% and 5%, by mass of cement is used,respectively.Water to cement ratio employed for above mentioned specimens is 0.6. The total number of 32 prototype slabs having steel and GFRP rebar of 6mm diameter as reinforcement are casted for conducting impact testing. Experimental results evaluated from prototype testing are presented in this chapter.

4.2 Impact Capacity

4.2.1 Low Height Impact

The outcomes of specimen casted for conducting test against low height impact, i.e. 650 mm has been displayed in Table 4.1.The first crack strength of SPL specimen against low height impact was found to be 10 strikes/blows while number of strikes to reach the ultimate strength found to be 21. Hence, 48% of total blows are required to initiate cracking in SPL. Similarly the first crack strength and ultimate strength of specimen SJ1L was found to be 13 and 27 strikes/blows, respectivley against low height impact i.e. 650 mm. Hence, after 49% of total blows, cracking process initiate in SJ1L . The number of blows required to initiate crackng in SJ3L specimen is 17 and number of blows required to achieve ultimate strength of SJ3L specimen is 37. Hence, 45.9% of total blows are required to initiate cracking in SJ3L specimen. The number of blows required to initiate crackng in SJ5L specimen is 18 and number of blows required to achieve ultimate strength of SJ5L specimen is 37. Hence, 48.6% of total blows are required to initiate cracking in SJ5L specimen.Similarly, in case of specimens having GFRP rebars, the first crack strength of GPL specimen against low height impact was found to be 11 strikes/blows while number of strikes to reach the ultimate strength found to be 20. Hence, 55% of total blows are required to initiate cracking in GPL.Similarly the first crack strength and ultimate strength of specimen GJ1L was found to be 11 and 28 strikes/blows, respectively against low height impact i.e. 650 mm. Hence, after 40% of total blows, cracking process initiate in GJ1L . The number of blows required to initiate crackng in GJ3L specimen is 24 and number of blows required to achieve ultimate strength of GJ3L specimen is 43.Hence, 55.9% of total blows are required to initiate cracking in GJ3L specimen. The number of blows required to initiate crackng in GJ5L specimen is 23 and number of blows required to achieve ultimate strength of GJ5L specimen is 41.Hence, 56% of total blows are required to initiate cracking in GJ5L specimen. Hence,GJ3L specimen shows greater resistance against low impact height.

Note: FC = first crack strength, US = ultimate strength.

The outcomes of low height impact testing can be seen in Figure 4.1.The specimens before and after conducting impact testing can be seen in Figure 4.3 along with their schematic drawing to have a clear interpretation of crack generation and propagation.The impact strength comparison of specimens in terms of percentages have been shown in Figure 4.1. The findings of SPL will be assign a reference value of 100% .The finding of remaining combination will be presented in terms of percentage increase or decrease relative to outcomes of SPL specimen. It can be observed that FC of GPL has been increased to 110%. Similarly, the FC of SJ1L and GJ1L have been augmented to 120% and 110%, respectively. Similarly, the FC of SJ3L and GJ3L have been augmented to 170% and 240%, respectively. Similarly, the FC of SJ5L and GJ5L have been augmented to 180% and 220%,

TABLE 4.1: Strength parameters against low height impact for specimen having Steel and GFRP rebars

Specimen Type	IH (mm)	IM (kg)	IF (N)	FC (Strikes)	US (Strikes)
SPL	650	1.75	11.15	10±0.5	21±1
SJ1L	650	1.75	11.15	13±1	27±2
SJ3L	650	1.75	11.15	17±2	37±5
SJ5L	650	1.75	11.15	18±1	37±7
GPL	650	1.75	11.15	11±0.5	20±2
GJ1L	650	1.75	11.15	11±1	28±3
GJ3L	650	1.75	11.15	24±1	43±2
GJ5L	650	1.75	11.15	23±2	41±3

respectively. It can be observed that US of GPL has been decreased to 95%. Similarly, the US of SJ1L and GJ1L have been augmented to 129% and 133%, respectively. Similarly, the US of SJ3L and GJ3L have been augmented to 176% and 205%, respectively. Similarly, the US of SJ5L and GJ5L have been augmented to 176% and 185%, respectively. These results shows that fiber addition change the concrete behavior against impact loading and will be helpful for sustaining more impact load.Hence,GJ3L specimen shows greater resistance against low impact height.

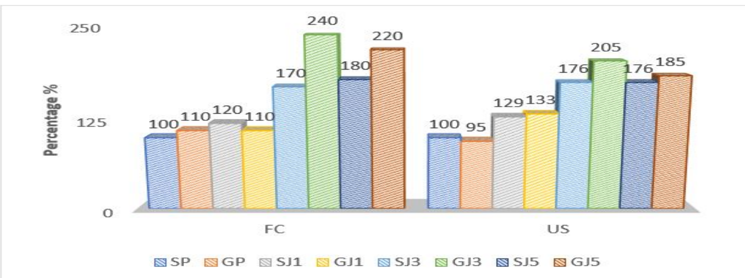

FIGURE 4.1: Low impact strength percentages

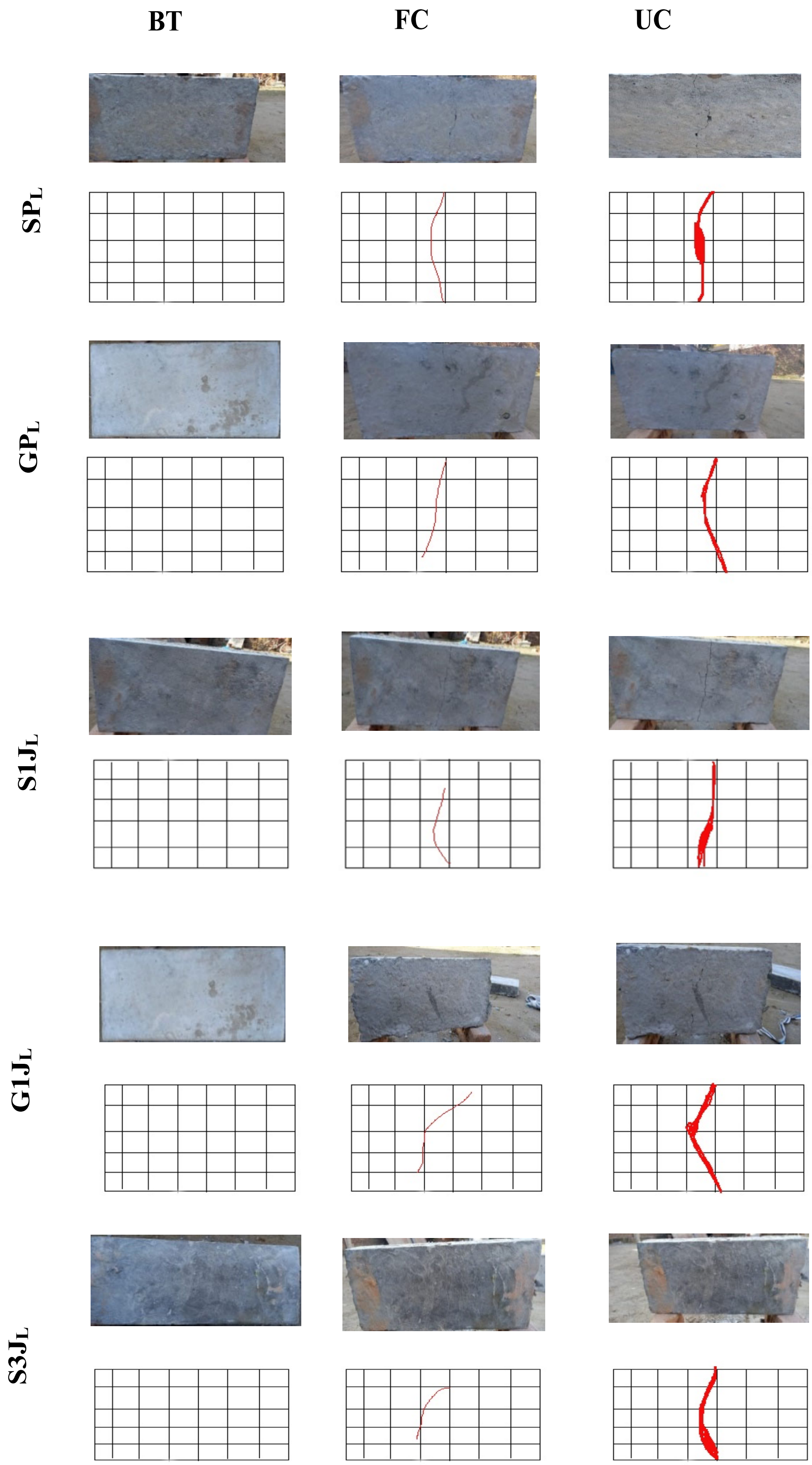

FIGURE 4.2: Specimens before and after testing for low height impact

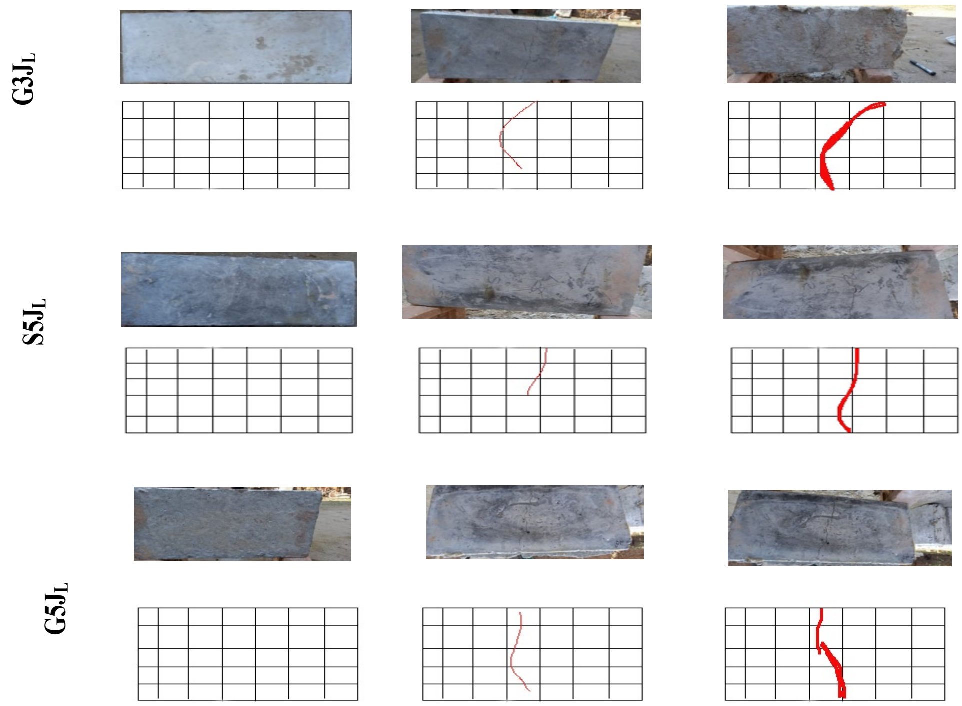

FIGURE 4.3: Specimens before and after testing for low height impact

4.2.2 High Height Impact

The outcomes of specimen casted for conducting test against high height impact, i.e. 950 mm has been displayed in Table 4.2 The first crack strength of SPH specimen against high height impact was found to be 6 strikes/blows while number of strikes to reach the ultimate strength found to be 13. Hence, 46% of total blows are required to initiate cracking in SPH. Similarly the first crack strength and ultimate strength of specimen SJ1H was found to be 8 and 17 strikes/blows, respectivley against low height impact i.e. 950 mm. Hence, after 47% of total blows, cracking process initiate in SJ1H . The number of blows required to initiate cracking in SJ3H specimen is 11 and number of blows required to achieve ultimate strength of SJ3H specimen is 22. Hence, 50% of total blows are required to initiate cracking in SJ3H specimen. The number of blows required to initiate cracking in SJ5H specimen is 11 and number of blows required to achieve ultimate strength of SJ5H specimen is 21. Hence, 52.3% of total blows are required to initiate cracking in SJ5H specimen. Similarly, in case of specimens having GFRP rebars, the first crack strength of GPH specimen against high height impact was found to be 5 strikes/blows while number of strikes to reach the ultimate strength found to be 12.Hence, 55% of total blows are required to initiate cracking in GPH. Similarly the first crack strength and ultimate strength of specimen GJ1H was found to be 7 and 19 strikes/blows, respectivley against high height impact i.e. 650 mm. Hence, after 37% of total blows, cracking process initiate in GJ1H.The number of blows required to initiate crackng in GJ3H specimen is 14 and number of blows required to achieve ultimate strength of GJ3H specimen is 23.Hence, 61% of total blows are required to initiate cracking in GJ3H specimen. The number of blows required to initiate crackng in GJ5H specimen is 13 and number of blows required to achieve ultimate strength of GJ5H specimen is 21.Hence, 61.9% of total blows are required to initiate cracking in GJ5H specimen.

The outcomes of high height impact testing can be seen in Figure 4.4.The specimens before and after conducting impact testing can be seen in Figure 4.5 along with their schematic drawing to have a clear interpretation of crack generation and propagation.The impact strength comparison of specimens in terms of percentages have been shown in Figure4.4 .

Table 4.2: Strength parameters against high height impact for specimen having Steel and GFRP rebars

Specimen Type	**IH (mm)**	**IM (kg)**	**IF (N)**	**FC (Strikes)**	**US (Strikes)**
SPH	950	1.75	16.30	6±0	13±1
SJ1H	950	1.75	16.30	8±1	17±2
SJ3H	950	1.75	16.30	11±1	22±2
SJ5H	950	1.75	16.30	11±1	21±3
GPH	950	1.75	16.30	5±0	12±0
GJ1H	950	1.75	16.30	7±1	19±1
GJ3H	950	1.75	16.30	14±1	23±3
GJ5H	950	1.75	16.30	13±0	21±2

The findings of SPH will be assign a reference value of 100% .The finding of remaining combination will be presented in terms of percentage increase or decrease relative to outcomes of SPH specimen.It can be observed that FC of GPH has been decreased to 83%.Similarly, the FC of SJ1H and GJ1H have been augmented to 133% and 117%, respectively.

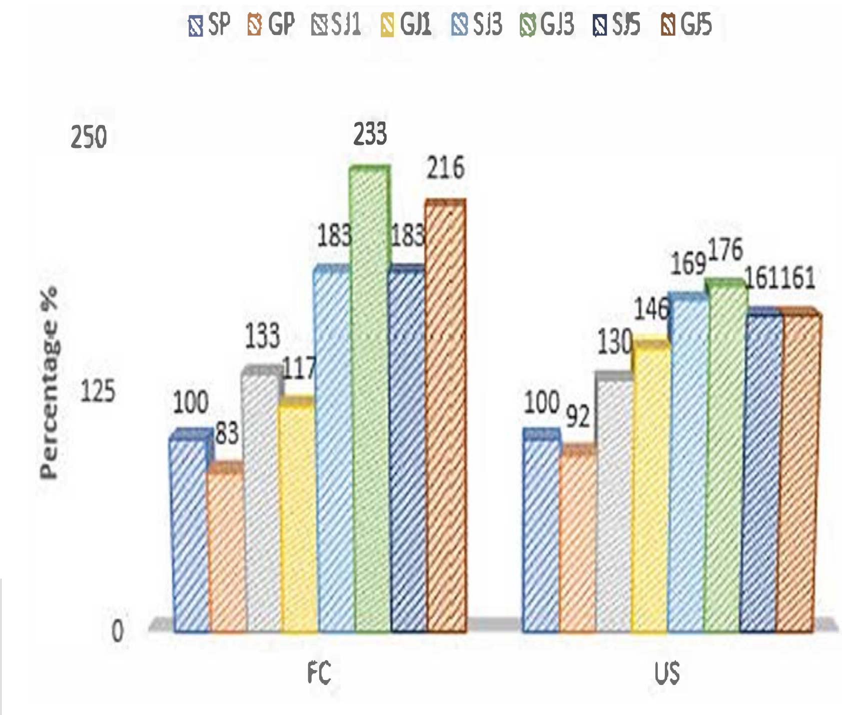

Figure 4.4: High impact strength percentages

Similarly, the FC of SJ3H and GJ3H have been augmented to 183% and 233%, respectively. Similarly, the FC of SJ5H and GJ5H have been augmented to 183% and 216%, respectively. It can be observed that US of GPH has been decreased to 92%.Similarly, the US of SJ1H and GJ1H have been augmented to 130% and 146%, respectively. Similarly, the US of SJ3H and GJ3H have been augmented to 169% and 176%, respectively. Similarly, the US of SJ5H and GJ5H have been augmented to 161% and 161%, respectively.These findings revealed that reinforcing of jute fibers in convectional concrete changes the performance in terms of resistance against impact.Also, the specimens having a GFRP-rebars with 3% jute fibers by mass of cement shows more resistance against impact in comparison with other combination of specimens.These results shows that fiber addition change the concrete behavior against impact loading and will be helpful for sustaining more impact load.

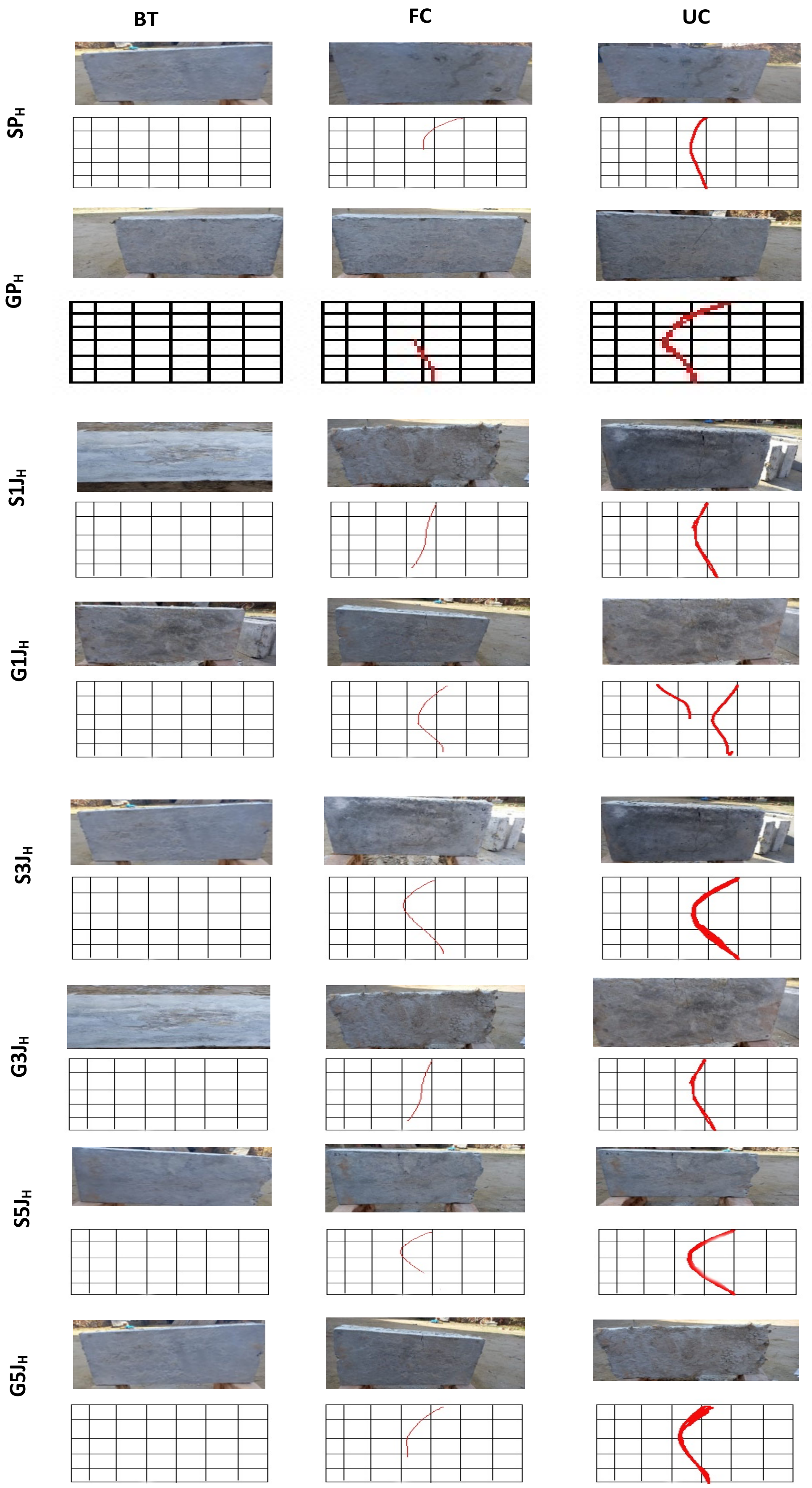

FIGURE 4.5: Specimen before and after testing of high height impact

4.2.3 Comparison with Previous Studies

The investigation of JFRC resistance with and without steel rebars against impact loading is done by Hussain and Ali[24]. Specimens were subjected to have an impact form a drop height of 600mm and 900mm with the help of 1.5kg hammer. Number of strikes/blows were counted till failure achieved. The ratio of first crack strength of JFRC having steel rebars to PC having steel rebars was found to be 1.7 and 1.67 for 600mm and 900mm drop height, respectively. The ratio of ultimate impact strength of JFRC having steel rebars to PC having steel rebars was found to be 1.32 and 1.52 for 600mm and 900mm drop height, respectively. The investigation of JFRC resistance with and without GFRP rebars against impact loading is done. Specimens were subjected to have a impact form a drop height of 700mm and 1000mm with the help of 2kg hammer.Number of strikes/blows were counted till failure achieved.

The ratio of first crack strength of JFRC having GFRP rebars to PC having GFRP rebars was found to be 1.69 and 1.75 for 700mm and 1000mm drop height, respectively. The ratio of ultimate impact strength of JFRC having GFRP rebars to PC having GFRP rebars was found to be 1.36 and 1.56 for 700mm and 1000mm drop height, respectively. The investigation of JFRC resistance with steel and GFRP rebars against impact loading by using modified pendulum impact apparatus is done by Ahmad and Ali [8].Two types of weight were used based upon which categorization has been done i.e. low impact for 2.215 kg and high impact for 2.925 kg. The ratio of first crack strength of JFRC having steel rebars to PC having steel rebars was found to be 1.75 and 1.39 for low and high impact, respectively. The ratio of ultimate impact strength of JFRC having steel rebars to PC having steel rebars was found to be 1.35 and 2.55 for low and high impact, respectively. Similarly, the ratio of first crack strength of JFRC having GFRP rebars to PC having GFRP rebars was found to be 2.23 and 3.02 for low and high impact, respectively. The ratio of ultimate impact strength of JFRC having GFRP rebars to PC having GFRP rebars was found to be 1.66 and 2.57 for low and high impact, respectively. However, in current research program, by keeping fibre length constant, three different fibre content i.e., 1%,3% and 5% are used for optimization of fibre content against impact loading. Specimens were subjected to have an impact form a drop height of 650mm and 950mm with the help of 1.75kg hammer. Number of strikes/blows were counted till failure achieved.

The ratio of first crack strength of JFRC with fibre content 1%,3% and 5% having steel rebars to PC having steel rebars was found to be 1.2, 1.7 and 1.8 for 650mm drop height, respectively. The ratio of first crack strength of JFRC with fibre content 1%,3% and 5% having steel rebars to PC having steel rebars was found to be 1.33, 1.83 and 1.83 for 950mm drop height, respectively. The ratio of ultimate strength of JFRC with fibre content 1%,3% and 5% having steel rebars to PC having steel rebars was found to be 1.28, 1.78 and 1.78 for 650mm drop height, respectively. The ratio of ultimate strength of JFRC with fibre content 1%,3% and 5% having steel rebars to PC having steel rebars was found to be 1.3, 1.69 and 1.61 for 950mm drop height, respectively. The ratio of first crack strength of JFRC with fibre content 1%,3% and 5% having GFRP rebars to PC having GFRP rebars was found to be 1, 2.18 and 2 for 650mm drop height, respectively. The ratio of first crack strength of JFRC with fibre content 1%,3% and 5% having GFRP rebars to PC having GFRP rebars was found to be 1.4, 2.8 and 2.6 for 950mm drop height, respectively. The ratio of ultimate strength of JFRC with fibre content 1%,3% and 5% having GFRP rebars to PC having steel rebars was found to be 1.4, 2.15 and 1.95 for 650mm drop height, respectively. The ratio of ultimate strength of JFRC with fibre content 1%,3% and 5% having GFRP rebars to PC having GFRP rebars was found to be 1.58, 1.92 and 1.75 for 950mm drop height, respectively. All the studies conducted are basically the relative comparison of PC and JFRC specimens. The outcomes of all studies in term of comparison are seems to be acceptable and have been presented in Table 4.3.Hence,it is concluded that the reinforcing of concrete with fibers will help in improvement in performance of concrete in terms of impact resistance,energy absorption capacity against impact loading and delaying in cracks. These findings revealed that reinforcing of jute fibers in convectional concrete changes the performance in terms of resistance against impact.These results shows that fiber addition change the concrete behavior against impact loading and will be helpful for sustaining more impact load.Thus, fiber addition change the concrete brittle behavior to ductile behavior.

4.3 Dynamic Properties

The outcomes of low height impact on dynamic properties of specimens before testing , after first crack strength and after ultimate strength have been presented in Table 4.4.The dynamic properties includes damping ratios in percentage, dynamic modulus in giga Pascal and longitudinal, transverse and torsional frequencies in KHz are calculated and presented in Table 4.4.It can be noticed that in case of longitudinal resonance frequencies before conducting impact testing are greater in case of SJ1L and GJ3L slabs than all other combination of specimens. After first crack impact strength SJ5L and GJ1L specimens show greater longitudinal resonance frequencies as compared with all other combination of specimens. SJ5L and GJ3L are dominant over all other specimens at ultimate strength against impact. Similarly, in case of transverse and torsional resonance frequencies, SJ5L and GJ1L are dominant over all other specimens at all the stages i.e., BT, FC, and US. Similarly, in case of dynamic elastic modulus, SJ1L and GJ3L are dominant. After utilization of impact strength, every specimen show increment in their damping value as seen in Table 4.4 The outcomes of high height impact on dynamic properties of specimens before testing , after first crack strength and after ultimate strength have been presented in Table 4.5.The dynamic properties includes damping ratios in percentage, dynamic modulus in giga Pascal and longitudinal, transverse and torsional frequencies in KHz are calculated and presented in Table 4.5.It can be noticed that in case of all resonance frequencies, greater values are observed in SJ5H and GJ3H when compared with all other casted specimens at all stages. Similarly, greater values are observed in SJ3H and GJ5H when compared with all other casted specimens at all stages in case of dynamic elastic modulus. Also, after utilization of impact strength, every specimen show increment in their damping value as seen in Table 4.5 .Note: FC = first crack strength, US = Ultimate strength, LI=low Impact, HI=High Impact. The decrease in percentage of dynamic elastic modulus at different damages stage have been shown in Figure 4.6 against low height and high height impact on specimens, respectively.These results shows that fiber addition change the concrete behavior against impact loading.Hence,fiber reinforcing causes improvement.

Table 4.3: Comparison with previous study of JFRC

Ref	**Impact**	**JFRC(fiber content)**	**Ratio (JFRC to PC)**			
			Steel		**GFRP**	
			FC	US	FC	US
Previous Work Hussain and Ali(2019)	600mm	5%	1.7	1.32	-	-
	900mm	5%	1.67	1.52	-	-
Previous Work Ahmad and Ali(2020)	LI	5%	1.75	1.35	2.23	1.66
	HI	5%	1.39	2.55	3.02	2.57
Current Study	650mm	1%	1.2	1.28	1	1.4
		3%	1.7	1.78	2.18	2.15
		5%	1.8	1.78	2	1.95
	950mm	1%	1.33	1.3	1.4	1.58
		3%	1.83	1.69	2.8	1.92
		5%	1.83	1.61	2.6	1.75

Table 4.4: Outcomes of low height impact on dynamic properties of slab specimens

	RF_{LON} (KHz)			RF_{TRAN} (KHz)			RF_{TOR} (KHz)			D_{EM} (GPa)			ξ (%)		
	BT	FC	US	BT	FC	US	BT	FC	US	BT	FC	US	BT	FC	US
SPL	3.2 ±0.17	2.1 ±0	1.4 ±0.09	3.6 ±0.15	2.9 ±0.12	1.9 ± 0.14	3.5 ± 0.13	2.2 ± 0.1	1.1 ± 0.21	21 ± 0.03	9.2 ±0.1	4.12 ± 0.3	1.3 ±0.2	2.4 ±0.4	2.9 ±0.12
GPL	3.50 ±0.15	2.3 ±0.11	1.2 ±0.21	3.59 ±0.53	2.68 ±0.19	1.4 ±0.5	1.6 ±0.5	1.3 ±0.46	0.7 ±0.65	25 ±0.5	11.1 ±0.12	3.03 ±2.1	1.5 ±0.1	2.6 ±0.3	4.4 ±0.11
SJ1L	3.6 ±0.55	2.01 ±0.32	1.37 ±0.05	1.50 ±0.64	1.34 ±0.42	0.8 ±0.32	3.5 ±0.14	2.4 ±0.33	1.1 ±0.78	27 ±0.94	8.5 ±1.1	3.94 ±0.1	2.5 ±0.4	3.0 ±0.32	3.9 ±0.09
GJ1L	3.55 ±0.43	2.5 ±0.04	1.9 ±0.32	3.63 ±0.33	2.87 ±0.1	1.45 ±0.41	1.4 ±0.41	1.1 ±0.21	0.76 ±0.94	26 ±0.6	12 ±3.1	7.6 ±0.15	2.31 ±0.2	3.9 ±0.15	4.7 ±0.1
SJ3L	3.27 ±0.25	2.35 ±0.3	1.47 ±0.17	1.5 ±0.09	1.1 ±0.21	0.67 ±0.19	1.28 ±0.51	0.87 ±0.14	0.57 ±0.59	21 ±1.1	4.7 ±05.3	2.3 ±3.1	2.62 ±0.13	3.5 ±0.13	4.7 ±0.6
GJ3L	3.82 ±0.44	2.4 ±0.21	2.1 ±0.11	1.5 ±0.12	1.09 ±0.14	0.54 ±0.11	3.5 ±0.09	2.2 ±0.56	0.9 ±0.13	30 ±3.1	13.1 ±2.1	9.27 ±4.3	2.47 ±0.23	4.12 ±0.11	6.1 ±1.1
SJ5L	3.3 ±0.41	2.57 ±0.13	1.50 ±0.143	4.4 ±0.44	3.1 ±0.18	2.3 ±0.53	3.63 ±0.88	2.5 ±0.48	1.2 ±0.65	19 ±1.1	6 ±1.7	2.19 ±2.1	2.66 ±0.15	3.6 ±0.16	4.9 ±3.3
GJ5L	3.68 ±0.63	1.93 ±0.14	1.7 ±0.121	3.5 ±0.65	2.6 ±0.43	1.21 ±0.6	1.31 ±0.9	0.76 ±0.122	0.43 ±0.13	28 ±2.1	7.8 ±3.1	6.07 ±2.3	2.61 ±0.11	4.17 ±0.14	6.0 ±1.1

TABLE 4.5: Outcomes of high height impact on dynamic properties of slab specimens

	RF_{LON} (KHz)			RF_{TRAN} (KHz)			RF_{TOR} (KHz)			D_{EM} (GPa)			ξ (%)		
	BT	FC	US	BT	FC	US	BT	FC	US	BT	FC	US	BT	FC	US
SPH	2.9 ±0.19	2.5 ±0	1.8 ±0.06	3.5 ±0.1	2.7 ±0.23	1.7 ±0.114	3.3 ±0.213	2.7 ±0.05	1.3 ±0.231	18 ±0.02	13 ±0.2	6.8 ±0.7	1.6 ±0.3	2.3 ±0.45	3.4 ±3.1
GPH	3.47 ±0.25	2.3 ±0.21	1.4 ±0.56	3.4 ±0.43	2.6 ±0.14	1.2 ±0.15	2.6 ±0.15	1.3 ±0.8	0.7 ±0.165	25.3 ±1.5	11.1 ±0.5	4.12 ±2.5	1.9 ±0.2	3.0 ±0.32	4.9 ±1.1
SJ1H	3.5 ±0.65	2.7 ±0.12	1.90 ±0.32	2.14 ±0.61	1.7 ±0.54	1.1 ±0.362	3.45 ±0.214	2.4 ±0.32	1.1 ±0.478	25.7 ±3.94	15.5 ±4.1	7.6 ±3.1	2.9 ±0.5	3.54 ± 0.39	4.6 ±2.09
GJ1H	3.59 ±0.41	2.7 ±0.09	1.6 ±0.67	3.53 ±0.55	2.4 ±0.3	1.2 ±0.451	3.4 ±0.541	1.1 ±0.21	0.76 ±0.294	27 ±2.6	15.3 ±1.1	5.4 ±1.15	2.8 ±0.1	4.0 ±0.23	5.1 ±3.1
SJ3H	3.5 ±0.35	2.74 ±0.35	2.1 ±0.19	2.5 ±0.02	1.6 ±0.61	0.98 ±0.219	3.29 ±0.251	0.87 ±0.17	0.57 ±0.759	26.6 ±1.4	15.8 ±2.6	9.2 ±4.1	2.9 ±0.16	3.91 ±0.7	4.8 ±1.6
GJ3H	3.7 ±0.46	2.8 ±0.261	1.7 ±0.12	3.7 ±0.16	2.54 ±0.12	1.50 ±0.311	3.57 ±0.19	2.2 ±0.36	1.5 ±0.213	28.7 ±2.2	16.5 ±2.4	6.07 ±3.4	3.4 ±0.28	5.3 ±0.2	6.8 ±1.5
SJ5H	3.51 ±0.49	2.59 ±0.132	2.03 ±0.14	4.2 ±0.41	2.9 ±0.10	1.78 ±0.653	3.6 ±0.78	1.9 ±0.248	1.2 ±0.165	25.8 ±1.1	14.4 ±1.3	8.7 ±2.9	3.2 ±0.3	4.2 ±3.16	5.6 ±2.3
GJ5H	3.71 ±0.43	2.9 ±0.144	1.8 ±0.18	3.63 ±0.54	2.2 ±0.41	1.46 ±0.26	2.9 ±0.13	1.76 ±0.15	1.43 ±0.613	28.9 ±3.1	17.8 ±2.1	6.8 ±3.2	4 ±0.18	5.37 ±1.1	7 ±1.4

The DEM of GP, GJ1, GJ3 and GJ5 have been decreased to 44.40%,46.15%,43.67 and 27.8% after FC and to 12.12%,29.23%,30.9% and 21.68% after US, respectively against low height impact. Similarly, The DEM of GP, GJ1, GJ3 and GJ5 have been decreased to 43.8%,56.67%,57.4%and 61.6% after FC and to 16.28%,20.0%, 21.15% and 23.53% after US, respectively against high height impact. The increase in percentage of damping ratio ξ at different damages stage have been shown in Figure 4.7 against low height and high height impact on specimens, respectively. The value of DEM before conducting test will be taken as reference value of 100%. The DEM of SP, SJ1, SJ3 and SJ5 have been decreased to 43.81%,31.48%,22.23 and 31.58% after FC and to 19.5%,14.59%,10.95% and 11.53% after US, respectively against low height impact. Similarly, The DEM of SP, SJ1, SJ3 and SJ5 have been decreased to 72.2%,60.31%,59.4%and 55.81% after FC and to 37.8%,29.6%,34.5% and 33.72% after US, respectively against high height impact.

The value of before conducting test will be taken as reference value of 100%. The of SP, SJ1, SJ3 and SJ5 have been increased to 184%,120%,133% and 135% after FC and to 223%,156%,179% and 184% after US, respectively against low height impact. Similarly, the of SP, SJ1, SJ3 and SJ5 have been increased to 143%,122%,134%and 131% after FC and to 212%,158%,165% and 175% after US, respectively against high height impact. The of GP, GJ1, GJ3 and GJ5 have been increased to 174%,168%,166% and 160% after FC and to 293%,203%,246% and 230% after US, respectively against low height impact. Similarly, the of GP, GJ1, GJ3 and GJ5 have been increased to 157%,142%,155%and 134% after FC and to 257%,182%,200% and 175% after US, respectively against high height impact. The trend increment in damping ratio against high height impact is as follow
$GP > SP > GJ3 > GJ1 > GJ5 > SJ5 > SJ3 > SJ1$

The trend increment in damping ratio against low height impact is as follow
$GP > GJ3 > GJ5 > SP > GJ1 > SJ5 > SJ3 > SJ1$
Hence,it is concluded that the reinforcing of concrete with fibers will help in improvement in performance of concrete in terms of impact resistance,energy absorption capacity against impact loading and delaying in cracks.The GJ3 specimens show more damping ratio, which represent its more resistance against impact loading.

a)

b)

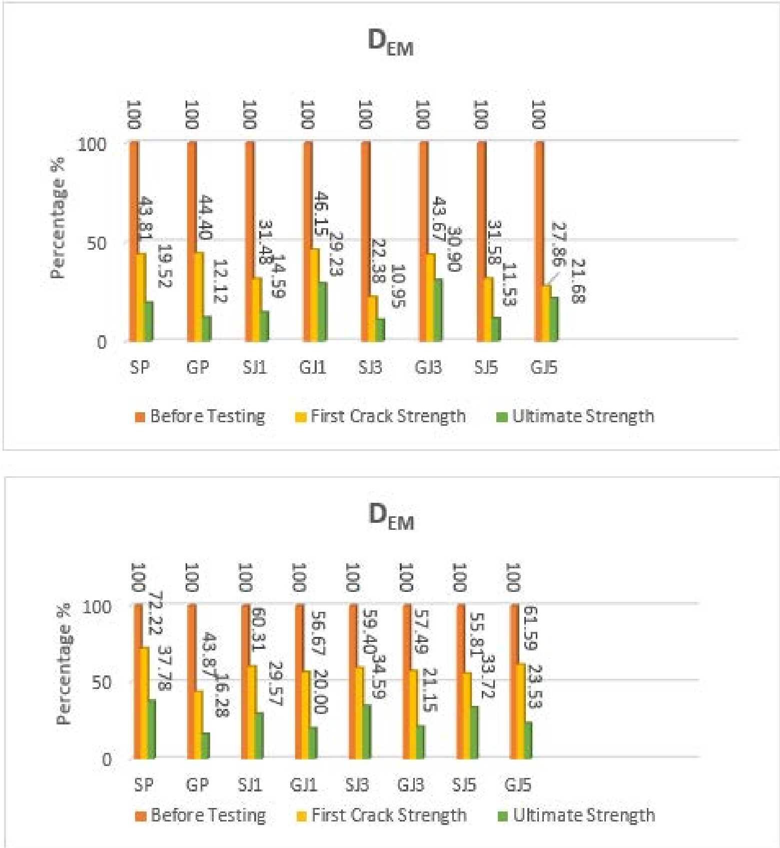

FIGURE 4.6: Percentage decrease in dynamic elastic modulus at different stages a) against low height impact, b) against high height impact.

a)

b)

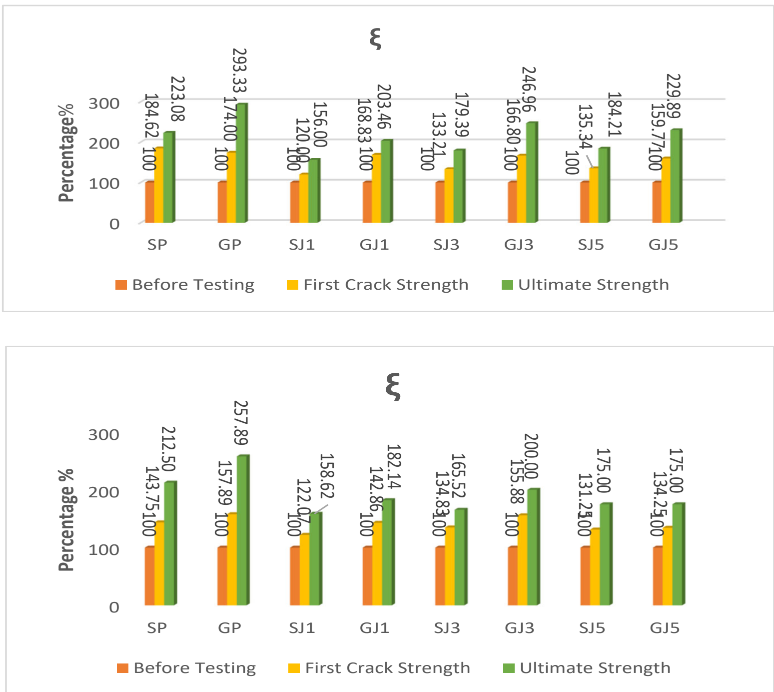

FIGURE 4.7: Percentage increase in damping ratio at different stages a) against low height impact, b) against high height impact. .

4.4 Summary

Impact Specimens are tested by using simplified impact testing approach. Two distinct drop height with constant mass are used to examine resistance against impact along with calculation of basic dynamic properties.The first crack strength of SJ5L, GJ3L, SJ3H and GJ3H show dominancy over all other combination against low and high height impact,respectively.Similarly, in the case of ultimate crack strength,SJ3L,SJ5L,GJ3L,SJ3H and GJ3H are dominant over all other combination.The result of comparison with previous studies also lies within satisfactory range.

Chapter 5

Discussion

5.1 Background

The findings of impact testing of specimens with different jute fiber content having steel rebars and GFRP rebars as reinforcement along with the basic dynamic properties have been discussed in detail in Chapter 4. Significant amount of increment in impact resistance and basic dynamic properties have been observed with the inclusion of jute fiber. The findings are then utilized to develop empirical relationship between fiber content and toughness Index. Also, empirical relationship between damping ratio of material and impact capacity have been also discussed in this chapter.

5.2 Empirical Relationship

5.2.1 Fiber Content against Toughness Index

Materials Properties are the main factor on which the structural performance against impact loading is dependent. Hence, concrete being the important materials, can directly affects the structural performance. Therefore, concrete performance against impact can be related to its flexural strength, energy absorption capacity and toughness. The bond present in concrete matrix plays an important

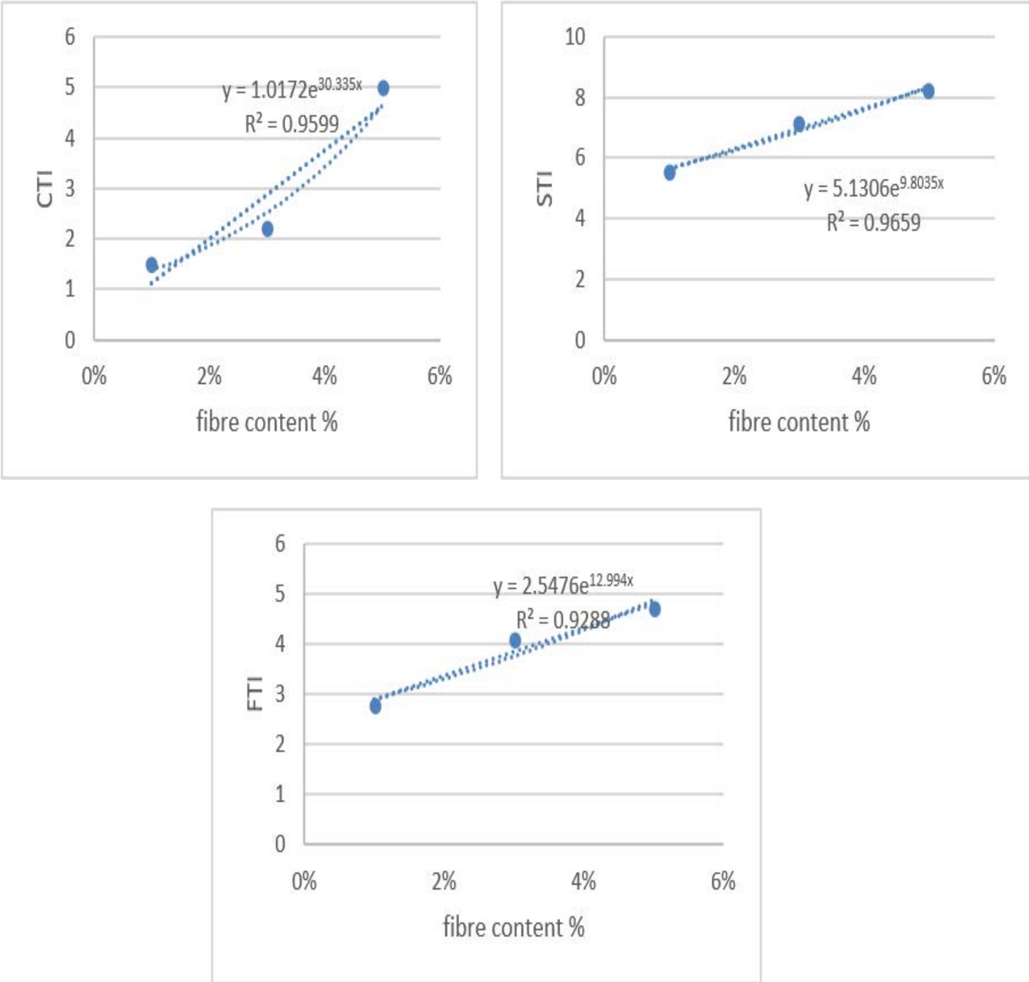

FIGURE 5.1: Development of empirical equations for fiber content and TI.

role in enhancing concrete performance. Fiber inclusions increase the bonding in concrete matrix. Hence, It is possible to obtain better concrete performance against impact loading. Concrete spalling can be related to its toughness. Toughness can be enhanced by reinforcing concrete with fibers which changes concretes brittle behavior toward ductile. Furthermore, fibers also play an important role in enhancing post cracking concretes capacity.

Empirical equations are determined by obtained results and best fit curve as shown in Figure 5.1. Empirical equations are given below:

$$CTI = 1.0172e^{30.335(Fibercontent\%)} \tag{5.1}$$

$$STI = 5.1306e^{9.8035(Fibercontent\%)} \tag{5.2}$$

$$FTI = 2.5476e^{12.994(Fibercontent\%)} \tag{5.3}$$

TABLE 5.1: Comparison Between Empirical equation and Experimental results

Specimen	Toughness Index (CTI)		% diff	Toughness Index (STI)		% diff	Toughness Index (FTI)		% diff
	Exp	Emp	-	Exp	Emp	-	Exp	Emp	
JF1	1.48	1.36	8.4	5.54	5.65	2	2.7	2.9	7.1
JF3	2.19	2.50	13	7.1	6.89	3	4	3.76	6.18
JF5	4.98	4.60	8	8.2	8.37	2	4.68	4.87	3.97

The comparison between experimental results and empirical equation results along with percentage difference have been presented in Table 5.1. This will help to check the precision of the developed empirical equation. The percentage difference between experimental toughness index and empirical toughness index of JF1 to JF5 in CTI, STI and FTI ranges between 8-14%,2-3% and 3.9-7.2%, respectively.

5.2.2 Damping ratio and Impact Strength

The ability of an element to absorb energy is directly related to its damping. The damping will help to reduces the structures response. The outcomes of experimental results of damping and impact strength are used to develop empirical relations by observing trends of curve. For all combinations of low and high height impacts, graphs were plotted separately as shown in Figure 5.2 which represents the empirical relations graph between damping ratio and No. of blows. The value of R^2 ranges from 84% to 100%.

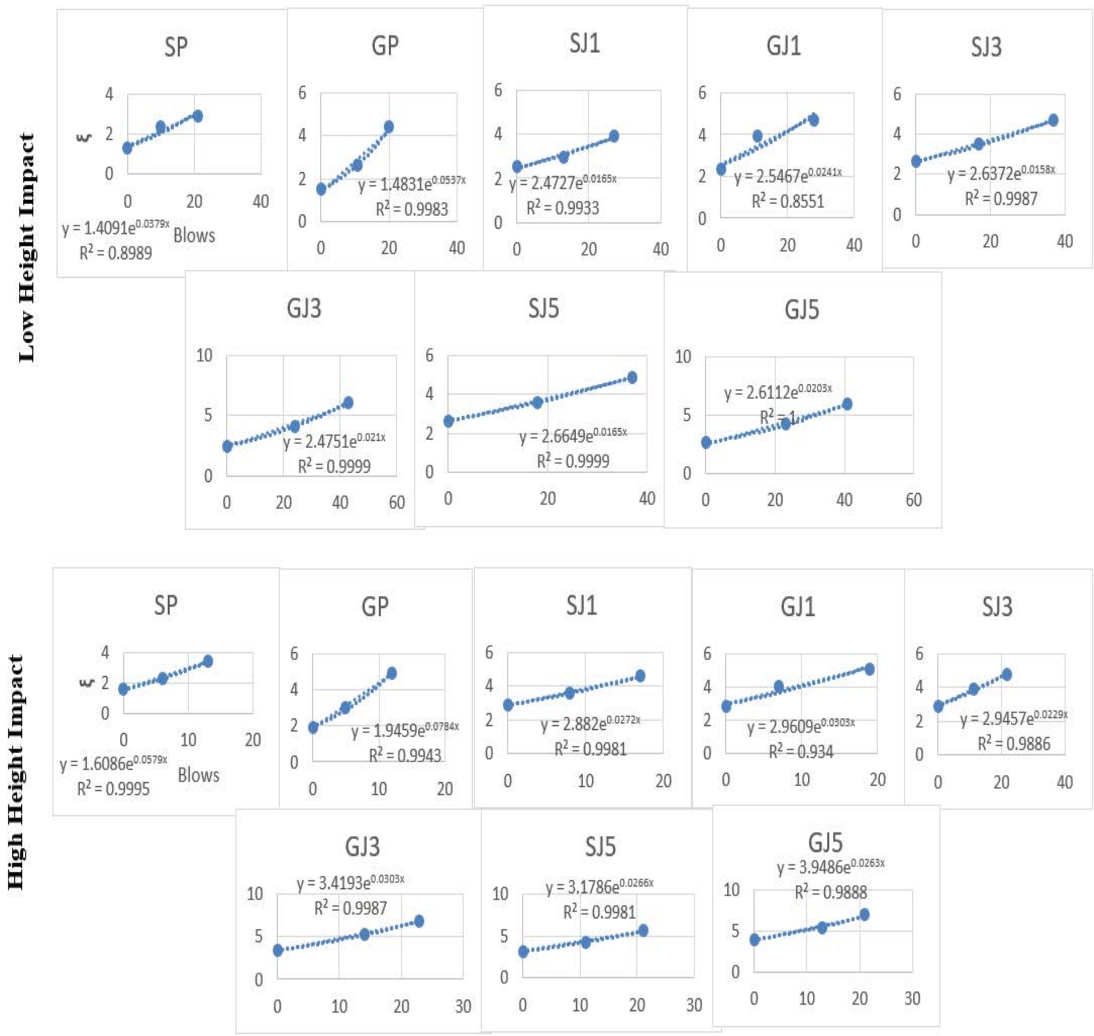

FIGURE 5.2: Development of empirical equations for Damping ratio and Impact Strength.

Table 5.2: Comparison Between Empirical equation and Experimental results of damping

Specimens	FC			US		
	Exp ξ	Emp ξ	% Diff	Exp ξ	Emp ξ	% Diff
SPL	2.4	2.05	15.38	2.9	3.12	7.38
SJ1L	3	3.06	2.18	3.9	3.85	1.09
SJ3L	3.5	3.42	2.07	4.7	4.72	0.42
SJ5L	3.6	3.57	0.80	4.9	4.90	0.069
GPL	2.6	2.6	2.63	4.4	4.33	1.5
GJ1L	3.9	3.31	16.14	4.7	4.996	5.9
GJ3L	4.12	4.08	0.87	6.1	6.088	0.18
GJ5L	4.17	4.14	0.48	6	5.9	0.38
SPH	2.3	2.256	1.93	3.4	3.3	0.23
SJ1H	3.54	3.57	0.94	4.6	4.55	1.014
SJ3H	3.91	3.78	3.18	4.8	4.85	1.22
SJ5H	4.2	4.25	1.40	5.6	5.53	1.24
GPH	3	2.87	4.08	4.9	4.98	1.64
GJ1H	4	3.6	9.40	5.1	5.26	3.25
GJ3H	5.3	5.23	1.30	6.8	6.83	0.56
GJ5H	5.37	5.56	3.61	7	6.83	2.44

The general form of empirical equation is:

$$\xi = a \times IH \times e^{b \times Blows} \tag{5.4}$$

where IH=Impact height in meters and Blows=no. of strikes. Values of a are 2.16,2.28,3.80,3.91,4.05,3.80,4.09 and 4.01 for SP, GP, SJ1, GJ1, SJ3, GJ3, SJ5 and GJ5, respectively for low height impact. Values of a are 1.68,2.04,3.03,3.11,3.1,3.59, 3.34 and 4.15 for SP, GP, SJ1, GJ1, SJ3, GJ3, SJ5 and GJ5, respectively for high height impact. Values of b are 0.0379,0.0537,0.0165,0.0241,0.0158,0.021,0.0165 and 0.0203 for SP, GP, SJ1, GJ1, SJ3, GJ3, SJ5 and GJ5, respectively for low height impact. Values of b are 0.0579,0.0784,0.0272, 0.0303,0.0229,0.0303,0.0266 and 0.0263 for SP, GP, SJ1, GJ1, SJ3, GJ3, SJ5 and GJ5, respectively for high height impact. The comparison between experimental results and empirical equation results of damping ratio along with percentage difference have been presented in Table 5.2. This will help to check the precision of the determined empirical equation. The percentage difference between experimental and empirical damping ratio lies between 0-15% against low height impact. The percentage difference between experimental and empirical damping ratio lies between 0-10% against high height impact. The Percentage difference is variable because different specimen has different behavior under impact loading.Hence,results lies in satisfactory range.

5.3 Relationship Between Prototype Behavior and Material Properties

Mechanical properties in Compression, splitting tensile and flexure are determined for plain concrete and jute reinforced concrete.Materials Properties are the main factor on which the structural performance against impact loading is dependent. Hence, concrete being the important materials, can directly affects the structural performance.

Prototype concrete slabs have been made with JFRC and PC and are reinforced with GFRP rebars as well with steel rebars, longitudinally and transversely.These slabs when tested under impact loading exhibited behavior similar to the material behavior mentioned above.The slabs without Jute fibers shows a brittle kind of failure, as they started to crack earlier as well as exhibit more cracks.Whereas, in the jute re-inforced slabs shows a ductile type of failure as they exhibit less number of cracks.Due to bridging effect of jute fibers,delay in cracking as well as less numbers of cracks appears in case of jute fiber reinforced concrete.Furthermore,energy absorption capacity as well toughness index also increases in case of prototype slabs having jute fiber.The empirical relation representing the first crack strength and Flexural toughness index is shown in Equation 5.5.Similarly,The empirical relation representing the ultimate strength and Flexural toughness index is shown in Equation 5.6.

$$FC = c * e^{d*(FTE)} \tag{5.5}$$

where c and d are constant.

$$US = a * e^{b*(FTE)} \tag{5.6}$$

where a and b are constant.

TABLE 5.3: Moment Capacity for specimens having Steel and GFRP rebars

Specimen Type	**Steel Rebar F_y(MPa)**	**GFRP Rebar F_y(MPa)**	**M_c(KN.m)**
SP	537	-	4.64
SJ1	537	-	4.66
SJ3	537	-	4.69
SJ5	537	-	4.70
GP	-	750	5.24
GJ1	-	750	5.33
GJ3	-	750	5.47
GJ5	-	750	5.50

Note: M_c=Moment Capacity

5.4 Analytical Modeling for Moment capacity of Prototype Slabs

There is a variation in resistance of concrete slabs against impact loading , prepared by using the different combinations of reinforcement and jute fibers content.Hence,different equations have been utilized for calculating the impact strength.The moment capacity of prototype slabs,have been presented in Table5.3. So, in terms of load carrying capacity, the combination of GFRP rebars with 5% jute fibers content dominates.There is increment in moment capacities of specimens having

GFRP rebars as compared to steel rebars.Hence, due to corrosion less nature and high strength as compared to steel rebars,GFRP rebars are preferable.

5.5 Summary

The empirical relation is developed between fiber content with toughness index and damping ratio with impact capacity. The percentage difference between experimental and empirical relations are calculated and results lies within satisfactory range.Hence, in terms of moment carrying capacity, the combination of GFRP rebars with 5% jute fibers content dominates.

Chapter 6

Conclusion and Future Work

6.1 Conclusions

In present research program, inclusion of locally available natural fiber i.e., Jute fibers in conventional concrete and replacement of convectional steel rebar with GFRP rebar for its application in concrete bridge slab to explore its strength in terms of impact resistance. Mix design ratio for (Cement: Sand: Aggregates) is 1:2:3 with 0.6 (w/c ratio). Length of 50mm Jute fibers and 1%,3% 5% jute fiber content by mass of cement are used. Diameter of 6mm for both rebars is used. The results of SP are taken as reference value for having the relative comparison with all other specimens combinations. The findings obtained from current program are as follows

- All the specimens having jute fibers as an additive, show its superiority over concrete specimens in terms of toughness, energy absorption and post cracking ability. Toughness index in case of split tensile and flexural, the values obtained for 3% and 5% fiber content are almost equal.The compressive strength obtained in case of specimens having 5% jute fiber content is greater than specimens with 1% and 3% jute fiber content.The split tensile strength and flexural strength obtained in case of 3% jute fiber content is greater than specimens with 1% and 5% jute fiber content.

- In case of first crack strength , the combination of steel with 5% fiber content SJ5 and combination of GFRP with 3% fiber content perform better against low height impact. In case of ultimate crack strength, the combination of steel with 3% and 5% fiber content SJ3 SJ5 and combination of GFRP with 3% fiber content GJ3 perform better against low height impact.
- In case of first crack strength , the combination of steel with 3% fiber content SJ3 and combination of GFRP with 3% fiber content perform better against low height impact.In case of ultimate crack strength,the combination of steel with 3% fiber content SJ3 and combination of GFRP with 3% fiber content GJ3 perform better against low height impact.
- The result of comparative studies lies within satisfactory range.
- The efficiency of jute fibers with GFRP and steel rebars against impact loading is justified as greater value of damping has been observed in all jute fiber specimens at different damages stage when compared with PC specimens. In case of percentage increment of damping ratio against different damages stage, GFRP without fiber content (GP) shows dominancy over all other combination for both low and high height impact,respectively.
- The probable trend of toughness Index against fiber content can be examine by empirical relation developed. The results obtained from empirical relation lies within acceptable range.
- The probable trend of damping against Impact capacity (No. of Blows) can be examine by empirical relation developed. The results obtained from empirical relation lies within acceptable range.

6.2 Future Work

The outcomes of current and previous studies suggest that inclusion of jute fibers in conventional reinforced concrete paved a way for construction industry in implementing sustainable practices.

- Finite Element modeling for exploring the impact resistance of slab by using experimental data of fiber reinforced concrete.
- Optimization of fiber length against Impact loading
- Durability of Fiber reinforced concrete and bond behavior between concrete and GFRP rebars needs to be explored.

Bibliography

[1] V. Aune, E. Fagerholt, M. Langseth, and T. Brvik, "A shock tube facility to generate blast loading on structures," *International Journal of Protective Structures*, vol. 7, no. 3, pp. 340–366, 2016.

[2] F. Liu, W. Feng, Z. Xiong, G. Tu, and L. Li, "Static and impact behaviour of recycled aggregate concrete under daily temperature variations," *Journal of Cleaner Production*, vol. 191, pp. 283–296, 2018.

[3] E. El-Salakawy, R. Masmoudi, B. Benmokrane, F. Brire, and G. Desgagn, "Pendulum impacts into concrete bridge barriers reinforced with glass fibre reinforced polymer composite bars," *Canadian Journal of Civil Engineering*, vol. 31, no. 4, pp. 539–552, 2004.

[4] M. V. Seica, J. A. Packer, and D. Z. Yankelevsky, "Blast and impact loading effects on glass and steel elements and materials," *Thin-Walled Structures*, vol. 134, pp. 384–394, 2019.

[5] Z. C. Muda, F. Usman, A. Syamsir, C. S. Yang, K. N. Mustapha, S. Beddu, S. Thiruchelvam, N. L. M. Kamal, M. A. Alam, A. H. Birima *et al.*, "Effect of thickness and fibre volume fraction on impact resistance of steel fibre reinforced concrete (sfrc)," in *IOP Conference Series: Earth and Environmental Science*, vol. 32, no. 1. IOP Publishing Ltd., 2016, p. 012026.

[6] H. Sadraie, A. Khaloo, and H. Soltani, "Dynamic performance of concrete slabs reinforced with steel and gfrp bars under impact loading," *Engineering Structures*, vol. 191, pp. 62–81, 2019.

[7] L. Jin, R. Zhang, G. Dou, J. Xu, and X. Du, "Experimental and numerical study of reinforced concrete beams with steel fibers subjected to impact

loading," *International Journal of Damage Mechanics*, vol. 27, no. 7, pp. 1058–1083, 2018.

[8] S. Ahmed and M. Ali, "Use of agriculture waste as short discrete fibers and glass-fiber-reinforced-polymer rebars in concrete walls for enhancing impact resistance," *Journal of Cleaner Production*, vol. 1, pp. 122–211, 2020.

[9] N. Sultana, S. Z. Hossain, M. S. Alam, M. Hashish, and M. Islam, "An experimental investigation and modeling approach of response surface methodology coupled with crow search algorithm for optimizing the properties of jute fiber reinforced concrete," *Construction and Building Materials*, vol. 243, pp. 118–216, 2020.

[10] R. Merli, M. Preziosi, A. Acampora, M. C. Lucchetti, and E. Petrucci, "Recycled fibers in reinforced concrete: A systematic literature review," *Journal of Cleaner Production*, vol. 248, pp. 119–207, 2020.

[11] M. Zakaria, M. Ahmed, M. Hoque, and A. Shaid, "A comparative study of the mechanical properties of jute fiber and yarn reinforced concrete composites," *Journal of Natural Fibers*, vol. 5, pp. 676–687, 2018.

[12] J.-S. Kim, H.-J. Lee, and Y. Choi, "Mechanical properties of natural fiber-reinforced normal strength and high-fluidity concretes," *Computers and Concrete*, vol. 11, no. 6, pp. 531–539, 2013.

[13] X.-G. Li, Y. Lv, B.-G. Ma, Q.-B. Chen, X.-B. Yin, and S.-W. Jian, "Utilization of municipal solid waste incineration bottom ash in blended cement," *Journal of Cleaner Production*, vol. 32, pp. 96–100, 2012.

[14] H. Campos, N. Klein, J. Marques Filho, and M. Bianchini, "Low-cement high-strength concrete with partial replacement of portland cement with stone powder and silica fume designed by particle packing optimization," *Journal of Cleaner Production*, vol. 1, pp. 121–228, 2020.

[15] A. Chandel, T. Shah, T. Shah, and D. Varde, "A comparative strength study of coir fibre reinforced concrete (cfrc) over plain cement concrete (pcc)," *Int J Mech Civil Eng*, vol. 13, no. 2, pp. 101–103, 2016.

[16] T. Zhang, Y. Yin, Y. Gong, and L. Wang, "Mechanical properties of jute fiber-reinforced high-strength concrete," *Structural Concrete*, vol. 21, no. 2, pp. 703–712, 2020.

[17] G. Ramakrishna and T. Sundararajan, "Impact strength of a few natural fibre reinforced cement mortar slabs: a comparative study," *Cement and concrete composites*, vol. 27, no. 5, pp. 547–553, 2005.

[18] M. S. Islam and S. J. Ahmed, "Influence of jute fiber on concrete properties," *Construction and Building Materials*, vol. 189, pp. 768–776, 2018.

[19] M. Affan, "Effect of freeze-thaw cycles on mechanical properties of jute fiber reinforced concrete for pavement," Master's thesis, Capital University, 2019.

[20] A. C. 318, *Building Code Requirements for Structural Concrete (ACI 318-14)[and] Commentary on Building Code Requirements for Structural Concrete (ACI 318R-14)*, 2014.

[21] D. B. Dittenber and H. V. GangaRao, "Critical review of recent publications on use of natural composites in infrastructure," *Composites Part A: applied science and manufacturing*, vol. 43, pp. 1419–1429, 2012.

[22] G. Ramakrishna and T. Sundararajan, "Studies on the durability of natural fibres and the effect of corroded fibres on the strength of mortar," *Cement and Concrete Composites*, vol. 27, pp. 575–582, 2005.

[23] F. Beshara, I. Shaaban, and T. Mustafa, "Nominal flexural strength of high strength fiber reinforced concrete beams," *Arabian Journal for Science and Engineering*, vol. 37, no. 2, pp. 291–301, 2012.

[24] T. Hussain and M. Ali, "Improving the impact resistance and dynamic properties of jute fiber reinforced concrete for rebars design by considering tension zone of frc," *Construction and Building Materials*, vol. 213, pp. 592–607, 2019.

[25] T. A. Elsayed, A. A. Elhefnawy, A. A. Eldaly, and G. M. Ghanem, "Hybrid fiber reinforced polymers rebars," *J. Adv. Mater*, vol. 43, pp. 65–75, 2011.

[26] W. J. Chin, Y. H. Park, J.-R. Cho, J.-Y. Lee, and Y.-S. Yoon, "Flexural behavior of a precast concrete deck connected with headed gfrp rebars and uhpc," *Materials*, vol. 13, no. 3, p. 604, 2020.

[27] E. A. Ahmed, C. Dulude, and B. Benmokrane, "Concrete bridge barriers reinforced with glass fibre-reinforced polymer: static tests and pendulum impacts," *Canadian Journal of Civil Engineering*, vol. 40, no. 11, pp. 1050–1059, 2013.

[28] K. M. Hossain, S. Alam, M. S. Anwar, and K. M. Julkarnine, "Bond strength of fibre-reinforced polymer bars in engineered cementitious composites," *Proceedings of the Institution of Civil Engineers-Construction Materials*, vol. 173, no. 1, pp. 15–27, 2020.

[29] M. Goldston, A. Remennikov, and M. N. Sheikh, "Experimental investigation of the behaviour of concrete beams reinforced with gfrp bars under static and impact loading," *Engineering Structures*, vol. 113, pp. 220–232, 2016.

[30] I. C. Higgins, "Impact of changes in the design methodology between the american concrete institutes draft code provisions for gfrp-reinforced concrete and the aci 440.1 r-15 guide for the design and construction of structural concrete reinforced with frp bars," Ph.D. dissertation, Widener University, 2020.

[31] A. Ejaz, "Investigation on concrete slab having jute fibers and gfrp rebars for bridge deck application," Master's thesis, Capital University, 2019.

[32] P. Li, H. Brouwers, and Q. Yu, "Influence of key design parameters of ultra-high performance fibre reinforced concrete on in-service bullet resistance," *International Journal of Impact Engineering*, vol. 136, p. 103434, 2020.

[33] J. Liu, C. Wu, Y. Su, J. Li, R. Shao, G. Chen, Liu, and Zhongxian, "Experimental and numerical studies of ultra-high performance concrete targets against high-velocity projectile impacts," *Engineering Structures*, vol. 173, pp. 166–179, 2018.

[34] W. Wang and N. Chouw, “Flexural behaviour of ffrp wrapped cfrc beams under static and impact loadings,” *International Journal of Impact Engineering*, vol. 111, pp. 46–54, 2018.

[35] M. Mastali, A. Dalvand, and A. Sattarifard, “The impact resistance and mechanical properties of reinforced self-compacting concrete with recycled glass fibre reinforced polymers,” *Journal of Cleaner Production*, vol. 124, pp. 312–324, 2016.

[36] T. M. Pham and H. Hao, “Prediction of the impact force on reinforced concrete beams from a drop weight,” *Advances in Structural Engineering*, vol. 19, no. 11, pp. 1710–1722, 2016.

[37] S. H. Ahmad, M. Arockiasamy, P. Balaguru, C. G. Ball, H. P. Ball Jr, G. B. Batson, A. Bentur, R. J. Craig, M. E. Criswell, S. Freedman *et al.*, “Measurement of properties of fiber reinforced concrete,” *ACI*, vol. 544, pp. 1–12, 1988.

[38] Z. Wu, P. Zhang, L. Fan, and Q. Liu, “Debris characteristics and scattering pattern analysis of reinforced concrete slabs subjected to internal blast loads–a numerical study,” *International Journal of Impact Engineering*, vol. 131, pp. 1–16, 2019.

[39] M. Zineddin and T. Krauthammer, “Dynamic response and behavior of reinforced concrete slabs under impact loading,” *International Journal of Impact Engineering*, vol. 34, pp. 1517–1534, 2007.

[40] A. ur Rehman, “Use of jute fibre reinforced concrete having gfrp rebars in thin shear wall to avoid catastrophic failure,” Master’s thesis, Capital University, 2020.

[41] M. Ali, A. Liu, H. Sou, and N. Chouw, “Mechanical and dynamic properties of coconut fibre reinforced concrete,” *Construction and Building Materials*, vol. 30, pp. 814–825, 2012.

[42] M. A. Vicente, J. Monguez, and D. C. Goez, “Computed tomography scanning of the internal microstructure, crack mechanisms, and structural behavior of

fiber-reinforced concrete under static and cyclic bending tests," *International Journal of Fatigue*, vol. 121, pp. 9–19, 2019.

[43] J. Mo, L. Zeng, Y. Liu, L. Ma, C. Liu, S. Xiang, and G. Cheng, "Mechanical properties and damping capacity of polypropylene fiber reinforced concrete modified by rubber powder," *Construction And Building Materials*, vol. 242, p. 118111, 2020.

[44] T. F. Lam and J. M. Yatim, "Mechanical properties of kenaf fiber reinforced concrete with different fiber content and fiber length," *Journal of Asian Concrete Federation*, vol. 1, no. 1, pp. 11–21, 2015.

[45] A. Standard, "C143/c143m-12."," *Test Method for Slump of Hydraulic-Cement Concrete." ASTM International*, 2012.

[46] S. Hamoush, M. Picornell-Darder, T. Abu-Lebdeh, and A. Mohamed, "Freezing and thawing durability of very high strength concrete," *American Journal of Engineering and Applied Sciences*, vol. 4, no. 1, pp. 42–51, 2011.

[47] C. ASTM *et al.*, "Standard test method for compressive strength of cylindrical concrete specimens," 2012.

[48] A. S. for Testing, M. C. C.-. on Concrete, and C. Aggregates, *Standard test method for splitting tensile strength of cylindrical concrete specimens*. ASTM International, 2011.

[49] A. I. C. C. on Concrete and C. Aggregates, *Standard Test Method for Flexural Strength of Concrete (using Simple Beam with Center-point Loading)*. ASTM international, 2010.

[50] S. Yue, Y. Qiu, N. Zhang, and M. Wang, "Analytical study of local damage on concrete slab subjected to a contact explosion," *Journal of Vibroengineering*, vol. 19, no. 2, pp. 908–929, 2017.